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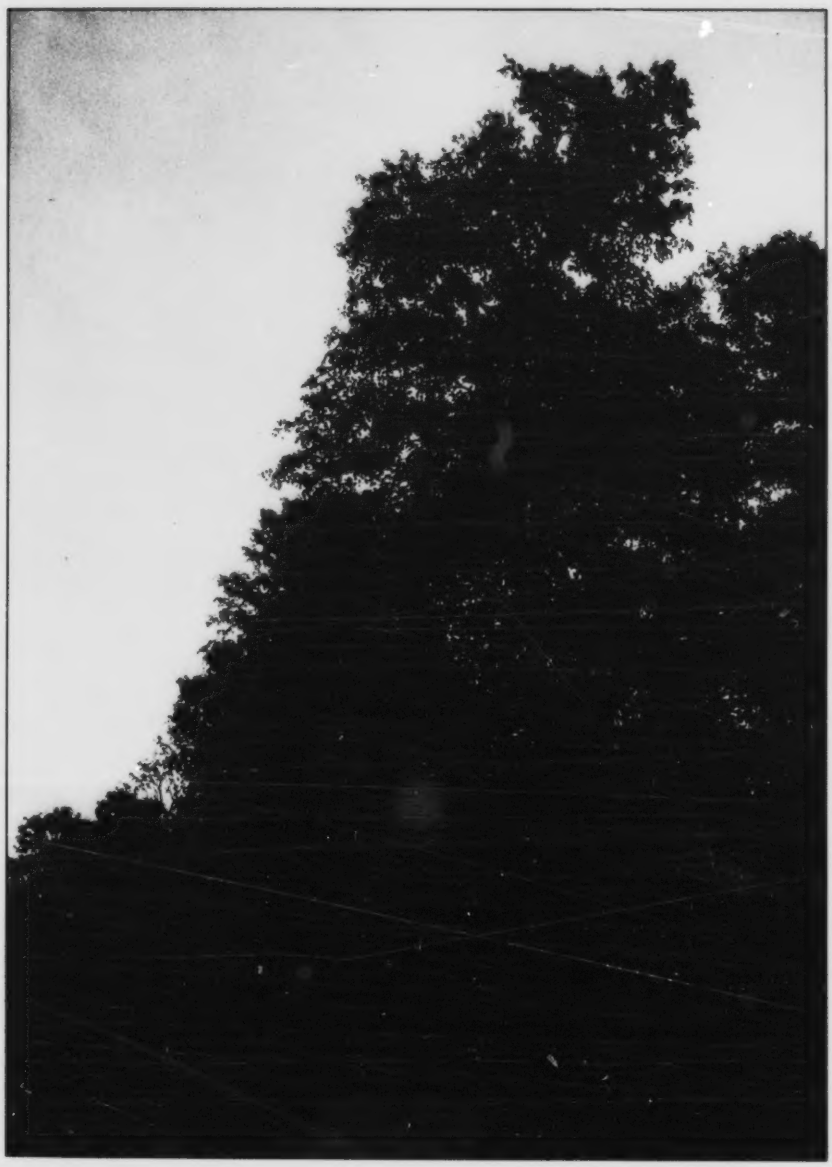
A SILVICULTURAL GUIDE FOR THE TOLERANT HARDWOODS WORKING GROUP IN ONTARIO



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LAKE SUPERIOR
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LAKE HURON
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REGIONS
REGIONAL HEADQUARTERS
1 NORTHWESTERN KENORA
2 NORTH CENTRAL THUNDER BAY
3 NORTHERN COCHRANE
4 NORTHEASTERN SUDBURY
5 ALGONQUIN HUNTSVILLE
6 EASTERN KEMPTVILLE
7 CENTRAL RICHMOND HILL
8 SOUTHWESTERN LONDON
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A SILVICULTURAL GUIDE FOR THE TOLERANT HARDWOODS WORKING GROUP IN ONTARIO

1990
Forest Resources Group

H.W. Anderson
B.D. Batchelor
C.M. Corbett
A.S. Corlett
D.T. Deugo
C.F. Husk
W.R. Wilson

Ontario
Ministry of
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Lyn McLeod
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FOREWORD

This silvicultural guide is one of several that are published as part of the Ontario Ministry of Natural Resources Science and Technology Series in Forestry.

Each silvicultural guide provides a description of the silvicultural characteristics of the working group[1] species and describes silvicultural practices for the working group. The guide reflects relevant literature and research, but equally important, the knowledge and experience of forestry staff in the management of the working group in Ontario and elsewhere.

The guides are primarily for use at the management unit level, where they are intended to be adapted and interpreted to meet local objectives and conditions. In particular, they are to be used by the management forester as a source of information and data that, together with local knowledge and experience, can form the basis for the development of silvicultural prescriptions in the timber management planning process.

George Tough
Deputy Minister

[1] Working group: An aggregate of forest stands that have the same predominant species (Ontario Ministry of Natural Resources [OMNR], Forest Resources Branch Policy No. FR 15 01 01 PO [1988], *Working Groups*).

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B.D. Batchelor, Management Forester, OMNR, Cambridge District
C.M. Corbett, Area Supervisor, Algonquin Forestry Authority, Huntsville
A.S. Corlett, Regional Forestry Specialist, OMNR, Algonquin Region
D.T Deugo, Unit Forester, OMNR, Bracebridge District
C.F. Husk, Scaling Auditor, OMNR, Northeastern Region, Sudbury
W.R. Wilson, District Biologist, OMNR, Minden District

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H.W. Anderson (Principal Author)
Research Scientist
Ontario Forest Research Institute
OMNR

INTRODUCTION

This guide has been prepared to assist in the planning, execution, and evaluation of silvicultural techniques appropriate to the Tolerant Hardwoods Working Group (THWG) on Crown lands in Ontario but could also be effectively used for similar lands in other jurisdictions. The information presented is designed to allow the forest manager to efficiently manage forest lands in terms of harvesting, regenerating, and tending, while maintaining other forest and environmental values. This guide is a revision and update of a similar OMNR guide produced by Bruce and Heeney (1974), and augments the manual *Management of Tolerant Hardwoods in Algonquin Provincial Park* (OMNR 1983).

The term *working group* is used to categorize all "productive" forest land in Ontario for the purposes of Forest Resources Inventory. The THWG is an aggregate of four interrelated working groups currently differentiated by Forest Resources Inventory: (i) Hard Maple, (ii) Yellow Birch, (iii) Hemlock, and (iv) Other Hardwoods. This guide provides information on seven principal species commonly found in these groups: hard (sugar) maple,[1] yellow birch, beech, hemlock, red oak, white ash, and black cherry.

These four inventory working groups have a natural relationship since all seven species may occur together as associates in most localities, often within a single stand. The term *tolerant hardwood*, however, is one of convenience, since not all associated species are tolerant of shade (e.g., yellow birch), and not all are hardwoods (e.g., hemlock is shade-tolerant but is a coniferous species).

This guide deals with the management of even-aged and uneven-aged forests that usually have been lightly cut over, often several times, in an uncontrolled manner. Such man-made disturbance, along with others such as those caused by fire, wind, and insect infestation, in combination with site factors and silvical characteristics of the species, have strongly influenced the tolerant hardwood forest in terms of stand structure, stocking levels, growth, and quality, as well as species composition.

Forest management is a planned process of interdependent treatments designed to modify, improve, utilize, and regulate the forest. The detail in this guide will assist in the development of suitable management strategies and the writing of effective silvicultural prescriptions based on interpretation of local site quality, species' silvical requirements, stand characteristics, economic product requirements, and biotic and environmental sensitivities.

The preparation of this guide has highlighted the need for a more comprehensive treatment of many technical concepts. A companion publication titled *A Tree-Marking Guide for the Tolerant Hardwoods Working Group in Ontario* (Anderson and Rice, in press) is currently being prepared, which, together with the list of pertinent literature provided in the "References Cited" section, is recommended when further detail is required.

---

[1] Scientific names for organisms are listed in the "Glossary of Scientific Names."

The goal of this guide is not to describe silvicultural practices that have historically been implemented but rather to provide the best knowledge currently available from published literature, research experiments, management trials, and the experience of staff members, thereby ensuring progressive, appropriate, and productive management of the Tolerant Hardwoods Working Group in Ontario.

1.0 MANAGEMENT OBJECTIVES

Silvicultural systems are designed to sustain and enhance the established forest industry in Ontario, while maintaining other non-timber forest values by applying principles of integrated resource management on the forest lands under the stewardship of the Ontario Ministry of Natural Resources.

Specific objectives are developed in the planning process to reflect the local nature of the forest and site, its environmental sensitivities, and the market for forest products. General management objectives for the THWG can be summarized as follows:

- To ensure a continuous and predictable supply, for the forest industry, of high-quality hardwood sawlogs and veneer bolts from the more productive forest sites by maintaining and enhancing their quality and yield through the application of appropriate silvicultural techniques.

- To maintain a healthy forest that satisfies the requirements of timber production, fish and wildlife habitat, aesthetics, recreation values, soil and water resources, and other social and environmental issues, through implementation of regional forest management strategies.

- To maintain or improve the forest genetic base by applying sound genetic principles when implementing silvicultural practices that employ selection criteria.

- To encourage the use of the full range of products available from all species, including fibre from logging residue and improvement cuttings, where markets are available.

2.0 CHARACTERISTICS OF THE WORKING GROUP

The satisfactory attainment of the management objectives in the THWG—which involves heterogeneous, qualitatively variable, and sometimes complex mixtures of the seven principal species (and other associated species)—requires a thorough understanding of many factors. This section will review the essential background material dealing with abiotic factors (values, distribution, site), biological factors (silvics, genetics, growth and yield, quality), and interactive concerns (wildlife habitat, environmental quality, social aspects). In the more accessible regions of the province where this working group exists, the manager must have a thorough knowledge and understanding of these concerns to successfully use the silvicultural prescriptions presented later in this guide.

2.1 Range and Commercial Importance

This working group occupies a broad geographic range in Ontario and is noted for its high-value products. This section will describe the geographic distribution of the seven principal species, their relative local abundance and importance, and the relative position of each species in a scale of commercial values, all of which affect the intensity of timber management that can be justified locally.

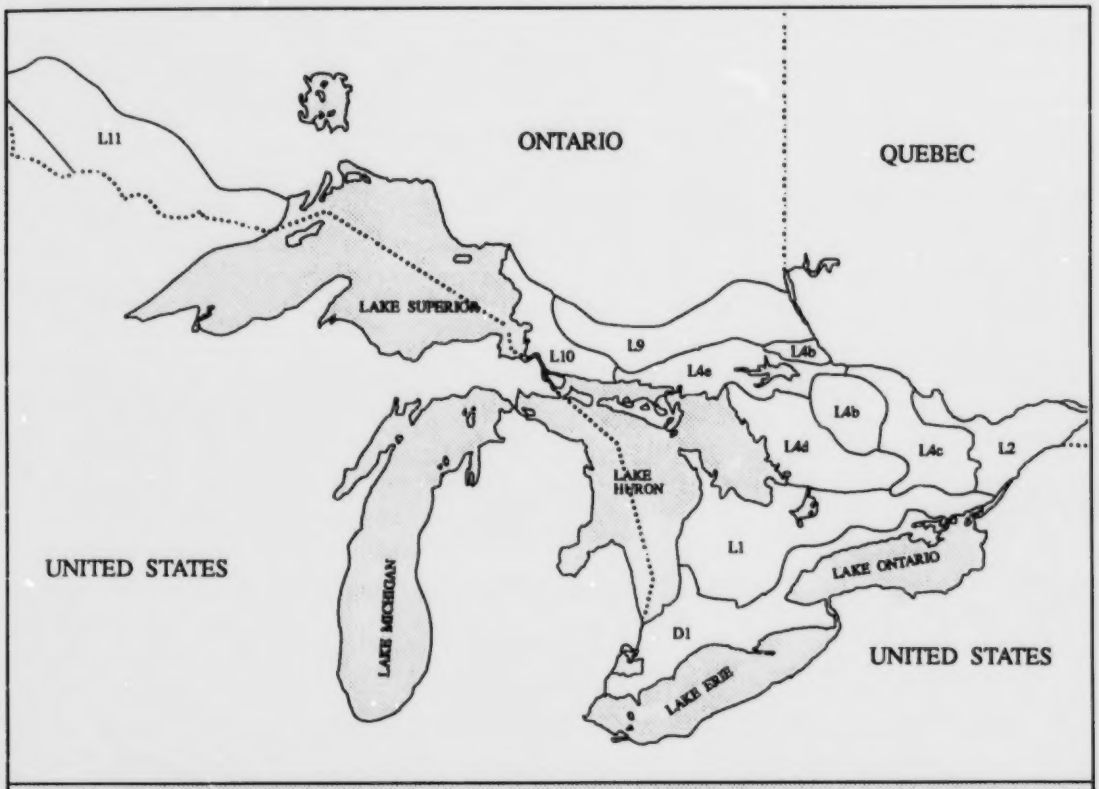
2.1.1 Range

The distribution of the forest tree species associated with the THWG is confined in Ontario to the Great Lakes-St. Lawrence and the Deciduous Forest Regions described by Rowe (1972). These regions represent major geographic zones, characterized vegetationally by a broad similarity both in physiognomy and in composition of the dominant tree species. The Great Lakes-St. Lawrence Forest Region is subdivided into sections (nine of which contain tolerant hardwoods), which are geographic areas "possessing an individuality which is expressed relative to other sections in a distinctive patterning of vegetation and of physiography." Climate is not used as a factor in any delineation.

The Deciduous Forest Region (Figure 1) contains a single section (D1) and represents the northern edge of a hardwood forest of widespread occurrence in the eastern United States. While it contains some species characteristic of the Great Lakes-St. Lawrence Forest Region to its north (such as hard maple, beech, and, locally, hemlock), it contains many species peculiar to this region such as walnut, sycamore, sassafras, swamp white oak, black gum, and others.

The Great Lakes-St. Lawrence Forest Region (Figure 1) is characterized by hemlock and yellow birch, as well as white and red pine. Associated with hemlock and yellow birch are other representatives of the THWG of wider distribution, such as hard maple, beech, red oak, white ash, and black cherry.

FIGURE 1: Forest regions and sections of Ontario associated with the THWG (from Rowe [1972])

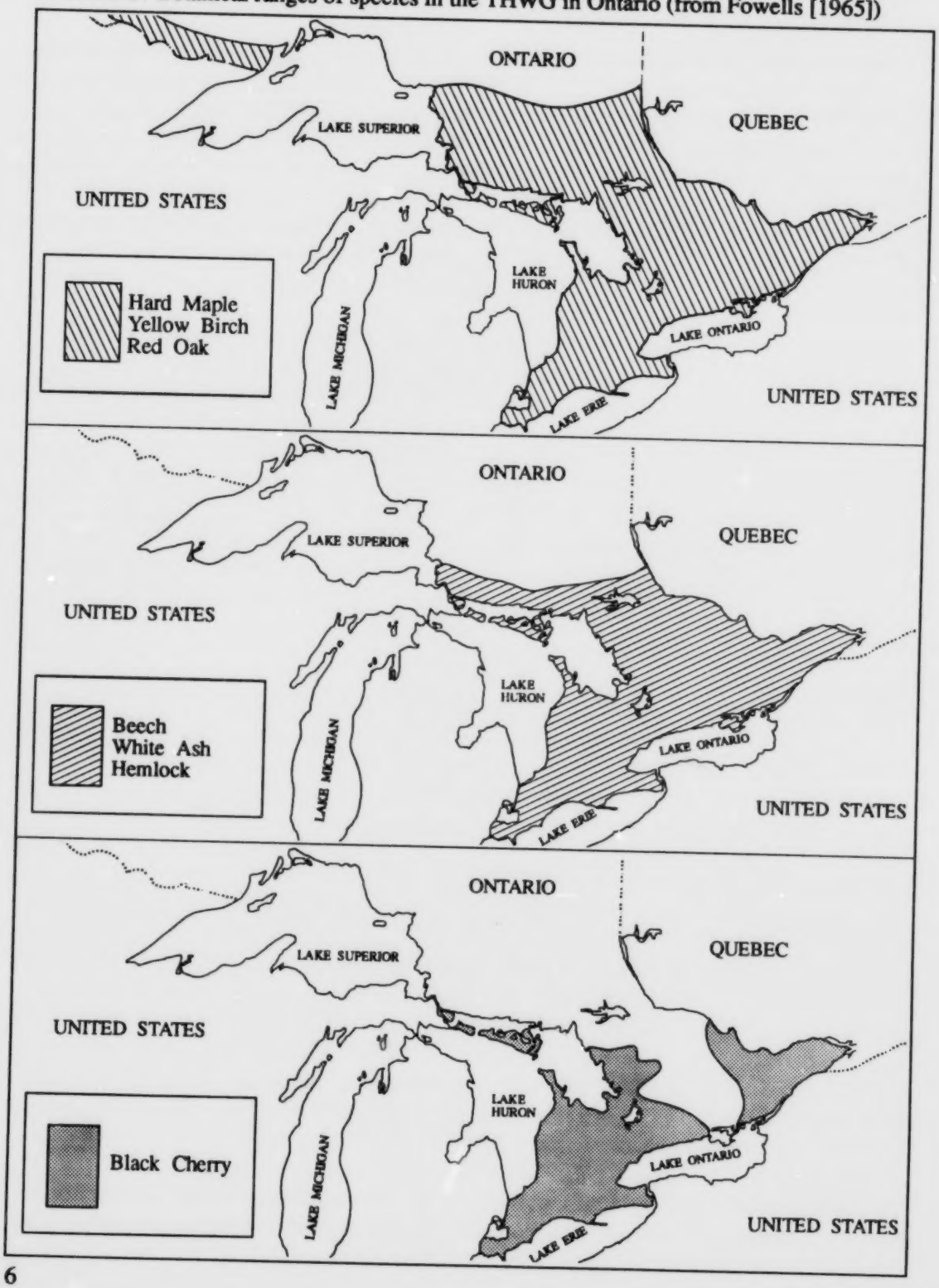


FOREST REGION	FOREST SECTION	
Great Lakes-St. Lawrence	L1	Huron-Ontario
Great Lakes-St. Lawrence	L2	Upper St. Lawrence
Great Lakes-St. Lawrence	L4b	Algonquin-Pontiac
Great Lakes-St. Lawrence	L4c	Middle Ottawa
Great Lakes-St. Lawrence	L4d	Georgian Bay
Great Lakes-St. Lawrence	L4e	Sudbury-North Bay
Great Lakes-St. Lawrence	L9	Timagami
Great Lakes-St. Lawrence	L10	Algoma
Great Lakes-St. Lawrence	L11	Quetico
Deciduous	D1	Niagara

The geographic (botanical) distributions of the seven species included in these working groups are shown in Figure 2. The significance of the seven species varies within nine of the sections in the Great Lakes-St. Lawrence Forest Region.

The limits of distribution and dominance of species within and among sections is related not only to the local history of disturbance but more specifically to variation in site and to the species'

FIGURE 2: Botanical ranges of species in the THWG in Ontario (from Fowells [1965])



particular ecological requirements. These local effects will be further discussed in Sections 2.2, "Site" and 2.3, "Silvics."

The commercial range of the THWG occupies most of Ontario south of the transitional forest. In the transitional forest (Sections L.9, L.10, and L.11) stands become more scattered, tending to occupy only the better sites, and have often been affected by a history of fires. In the extreme northwest (L.11), THWG species occur as outliers.

As noted earlier, the THWG comprises four inventory working groups. The commercial range of the Hard Maple Working Group extends throughout its distribution, although its quality may often be severely restricted in the northern portions of the transitional forest (Sections L.9, L.10, and L.11). The Yellow Birch Working Group occurs commercially from its northern limit southward to Section L.4d, but rarely attains a dominant stand position in more southerly areas of Section L.1 or in the Deciduous Forest Region. The Hemlock Working Group is significant from its northerly limit in Section L.4e to the southern limit of the Great Lakes-St. Lawrence Forest Region (Section L.1). While it is not uncommon to find representatives of all or many of the seven species within a single working group (subject to range limitations), the Other Hardwoods Working Group becomes more common toward the southern portion of the province, generally south of Section L.4e. Most of the four working groups become more species-rich as their occurrence moves south. Within the general ranges, however, higher-elevation effects may eliminate local occurrences of some species; this happens, for example, in Section L.4b with white ash, black cherry, and red oak.

Minor species components occurring less abundantly and less regularly in the northern part of the THWG range are basswood, red maple, black ash, white elm, white pine, white spruce, and red spruce. These associations are similar to those found in the northern hardwood and Appalachian mixed hardwood forest types of the United States (Burns 1983). Further south, the tolerant hardwoods may blend with "Carolinian" species (including black maple) to produce a very heterogeneous hardwood forest.

2.1.2 Commercial Importance

2.1.2.1 Supply

Including all ownerships (Crown and patent lands), 98 per cent of the provincial tolerant hardwood growing stock (including hemlock) of approximately 523 million cubic metres of gross total volume (GTV), distributed over 3.9 million hectares, is located in five Administrative Regions of OMNR—namely, Algonquin, Northeastern, Eastern, Central, and Southwestern Regions (OMNR 1986d). The most significant for the THWG, on an area basis, are Algonquin Region (35 per cent) and Northeastern Region (29 per cent). On a strictly regional basis, however, the THWG (excluding hemlock) comprises 15 per cent, 46 per cent, and 58 per cent of the total Crown production forest (area basis) in the Northeastern, Algonquin, and Central Regions, respectively. These species, therefore, may have a much greater local significance than might be implied by their overall provincial contribution.

The Hard Maple Working Group is the largest in the THWG, constituting 71 per cent of the area and 74 per cent of the gross total volume, followed by Other Hardwoods (21 per cent and 16 per cent, respectively), Yellow Birch (5 per cent and 6 per cent), and Hemlock (3 per cent and 4 per cent). Hemlock is concentrated, on an area basis, in Algonquin Region (58 per cent) and Northeastern Region (25 per cent), while yellow birch is most widely distributed in Northeastern Region (70 per cent) and Algonquin Region (21 per cent). Other Hardwoods have 37 per cent of their area in Algonquin Region, 24 per cent in Eastern Region, and only 8 per cent in Northeastern Region. (These values for other hardwoods do not include white birch or poplar.)

2.1.2.2 Consumption

There has been a trend of increasing volumes of all relevant species harvested from Crown lands over the period 1982-86 (OMNR 1987e). Of the 0.87 million cubic metres of the THWG harvested in 1986, 42 per cent were hard maple, 13 per cent were yellow birch, 8 per cent were hemlock, 5 per cent were beech, 3 per cent were oak, less than 1 per cent were ash and cherry, and 30 per cent were mixed (undifferentiated tolerant hardwoods). Of this harvested material, 50 per cent was used as sawlog material, and 20 per cent was taken as pulpwood. The remaining 30 per cent was the mixed hardwood category, used exclusively for fuelwood.

The THWG species harvest represents 4.4 per cent of the provincial total harvest and contributes 3.7 per cent of stumpage value returns (although the "bonus" contribution included in this value is relatively high, at 17.2 per cent). About 70 per cent of THWG stumpage revenues come from hard maple and yellow birch (OMNR 1987e). In addition, however, funding for forest management activities conducted in Algonquin Provincial Park by the Algonquin Forestry Authority is derived from an operating reimbursement from OMNR and the retention of approximately 90 per cent of the stumpage fees normally remitted to the Crown. In the fiscal year 1986/87, the Algonquin Park THWG contributed some 192 000 m^3 of harvested veneer, sawlog, boltwood, pulpwood, and fuelwood, generating a stumpage value of approximately $453 000.

Any silvicultural practice that upgrades a stand's sawlog or veneer log yield will increase relative stumpage value. However, a more representative measure of actual value is obtained by considering product price and associated "value added" (Johnson [1987]; OMNR [1986c]).

2.1.2.3 Economic Value by Species and End-product

The industrial value of the semi-tolerants (yellow birch, red oak, white ash, and black cherry) tends to be somewhat higher than that of the more shade-tolerant sugar maple and beech. There is considerable variance within those groupings as well, with red oak grade 1 sawlog material often having values that are more than 30 per cent greater than those for yellow birch. Actual values fluctuate considerably with changing market conditions (which in turn reflect consumer preference and wood supply), and would have to be considered when the manager is choosing the appropriate silvicultural system to achieve the desired species composition of the residual forest.

The value differential related to quality is also quite significant. Grade 1 tolerant hardwood sawlogs commonly show a delivered-to-the-mill value at least 30 per cent greater than grade 2. A quality veneer log may have more than double the commercial value of a sawlog of similar size. In hardwoods value is based on appearance and freedom from defect, while in softwoods it is related primarily to strength. The various grades of hardwood lumber maintain price differentials that reflect these quality criteria. The price of the best grade (FAS) is commonly 40 per cent higher than that of a medium grade (No. 1 Common), which in turn is often 60 per cent higher than the lowest commercial grade (No. 3 Common). Potential product value must be a consideration in allocating management funds to stands in which site productivity makes possible the production of high-quality material.

2.1.2.4 Significance to Industry

There are 268 sawmills, 12 veneer mills, and 4 pulp mills within the province that use tolerant hardwoods as at least a portion of their raw material. Ninety per cent of the sawmills and 58 per cent of the veneer mills are located in southerly portions of Ontario.

Most of the processed lumber and veneer material is directed to the furniture, flooring, panelling, ties, pallet, and coffin/casket industries. Each stage of manufacture, from stump to final product, contributes to the value added, with actual value added being a function of species. Table 1 shows the relative value added for a range of tolerant hardwoods during the production of lumber.[2]

2.2 Site

The distribution, character, and productivity of Ontario's forests are controlled by the interacting effects of climate, landform, soils, and vegetation. This control is especially true for the tolerant hardwood forests of the province, in which both performance and quality are sensitive to both macro- and micro-variations in site. Procedures related to evaluating site potential for THWG stands are outlined more specifically in *A Tree-Marking Guide for the Tolerant Hardwoods Working Group in Ontario* (Anderson and Rice, in press).

2.2.1 Climate

The effect of climate on the tolerant hardwood forests of Ontario is modified by landform and proximity to the Great Lakes. Two climatic characteristics that appear to significantly affect the hardwoods are (i) the decrease in summer temperature from south to north, with the isotherms showing a "continental" tilt from northwest to southeast; and (ii) the trend of atmospheric humidity from a drier west to a more humid east. In addition, weather is quite variable because of the occurrence of storm-tracks of continental-polar and -tropical air masses (Hills 1959).

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[2] Stephenson, N. (formerly General Manager, G.W. Martin Logging Co., Harcourt, Ontario). Personal Communication.

TABLE 1: Value Added (1988 $/Mfbm)* During the Production of Lumber

Species	Production Cost ($)+	Value Added Through Manufacturing ($)•	Final Value of Lumber Average ($) {$ Range}*
Hard maple	230	150	380 {75-1100}
Beech	230	100	330 {75-800}
Yellow birch	230	150-200	350-400 {75-1500}
Red oak	230	300	530 {75-2500+}
White ash	230	250	480 {0-1200}-little low end
Basswood	230	200	430 {0-1300}
Black cherry	230	200	430 {75-1500}

Notes:

* $/Mfbm = dollars per thousand-foot board measure.
+ "Production Cost" is free-on-board (FOB) to the mill, including crown dues, harvest cost, hauling, etc.
• Value ranges shown depend on the range of grade available for manufacture. The "Value Added Through Manufacturing" represents the average realized given the general quality of material available.

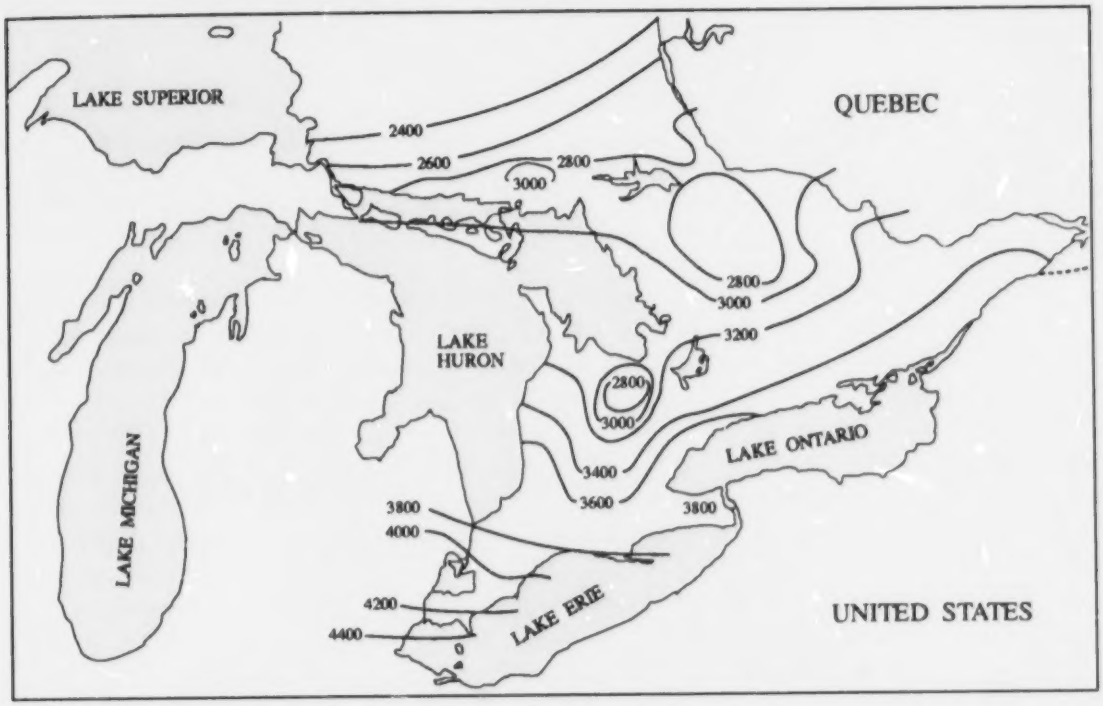
Precipitation varies from 66 to 102 cm per year, depending on the location, slope, and elevation of land masses relative to water masses and prevailing wind direction. Areas in the lee of large lakes have more cloud, more precipitation, and more moderate temperatures than other locations. The highest precipitation levels occur at elevations of 360 to 425 m on slopes east of Lake Huron, while further to the east in the Ottawa Valley drier conditions prevail in the rain-shadow of the Algonquin Highlands.

Minimum temperatures are substantially higher within 30 km of any of the Great Lakes, reducing the risk of early fall frost and lengthening the growing season by as much as 10 days. The shortest frost-free period (in days) and the fewest growing degree-days[3] occur in Algoma (100 and 1333, respectively) and in the Algonquin Highlands (90 and 1555), while the highest values for these climatic features have been recorded on Pelee Island (180 and 2444) (Brown et al. 1974). (See Figure 3.)

Local climate is affected by aspect and slope, southern exposures being hotter and drier than northern. Fog and frost-pockets occur in air-locked depressions, encouraging the development of vegetation characteristic of more northerly regions. Similarly, protected upper slopes with good air drainage and southerly aspects have vegetation representative of more southerly areas

[3] Brown et al. (1974) give growing degree-days (GDD) based on the accumulated number of degrees Fahrenheit of mean daily temperature above a base of 42°F. Text values in this guide are Celsius conversions based on the following relationship: GDD (°C) = GDD (°F) / 1.8.

FIGURE 3: Distribution of growing degree-days (based on Fahrenheit degrees) in southern Ontario (from Brown et al. [1974])



(Hills 1960). Recently, MacIver (1986) has produced a series of climatograms, developed for more than 100 long-term climatic stations in Ontario. These climatograms graphically summarize a variety of climatic factors and provide a means of comparing the climate of different areas.

2.2.2 Soils

Field methods for describing soils can be found in the *Field Manual for Describing Soils* (OIP 1985); the methods are based on those described by the Canada Soil Survey Committee (1987), and the Expert Committee on Soil Survey (1983).

The tolerant hardwood forests occur on lands that have two distinct zones in Ontario. The southern forests (those areas approximately south of the city of Barrie) occupy fertile, relatively deep soils, developed from Paleozoic shales and limestones, while those in the north occur on less fertile, relatively shallow soils mainly developed from Precambrian granites and gneisses. Most of the surface of this land has been moulded by moving continental ice sheets or is covered by glaciofluvial and lacustrine deposits and remains relatively unaltered as an assemblage of depositional landforms (Chapman and Putnam 1984).

In the southern portion, the bedrock surface has a low topographic relief, except for the Niagara escarpment and the Dundalk upland (520 m above sea level asl), and the Oak Ridges moraine (390 m asl). A lower arch of Precambrian bedrock is exposed east of Kingston (the Frontenac

Axis), while much of the Ottawa Valley is less than 60 m asl. The overburden is usually deep, composed of calcareous soils; however, rock plains of dolostone and limestone supporting relatively shallow deposits occur northward from Kingston toward Ottawa, and on Manitoulin Island and the Bruce Peninsula (Chapman and Putnam 1984).

In the northern zone, the relief is more pronounced; it consists of hills, ridges, and plains. The Algonquin Highlands is a peneplain (490 to 580 m asl) dissected by valleys; local relief can vary by 15 to 60 m over very short distances. Glacial overburden is shallow, deficient in lime (low-base), with many rock outcrops. The valleys are often blocked by glacial debris and occupied by lakes.

Glaciation has created a complex configuration of moraines, spillways, drumlins, abandoned shorelines, and other deposits (Chapman and Putnam 1984). Because the glacial overburden was transported, deposited, and reworked by ice and water, the lithology of the parent soil materials may differ considerably from that of the underlying bedrock (Burger 1967).

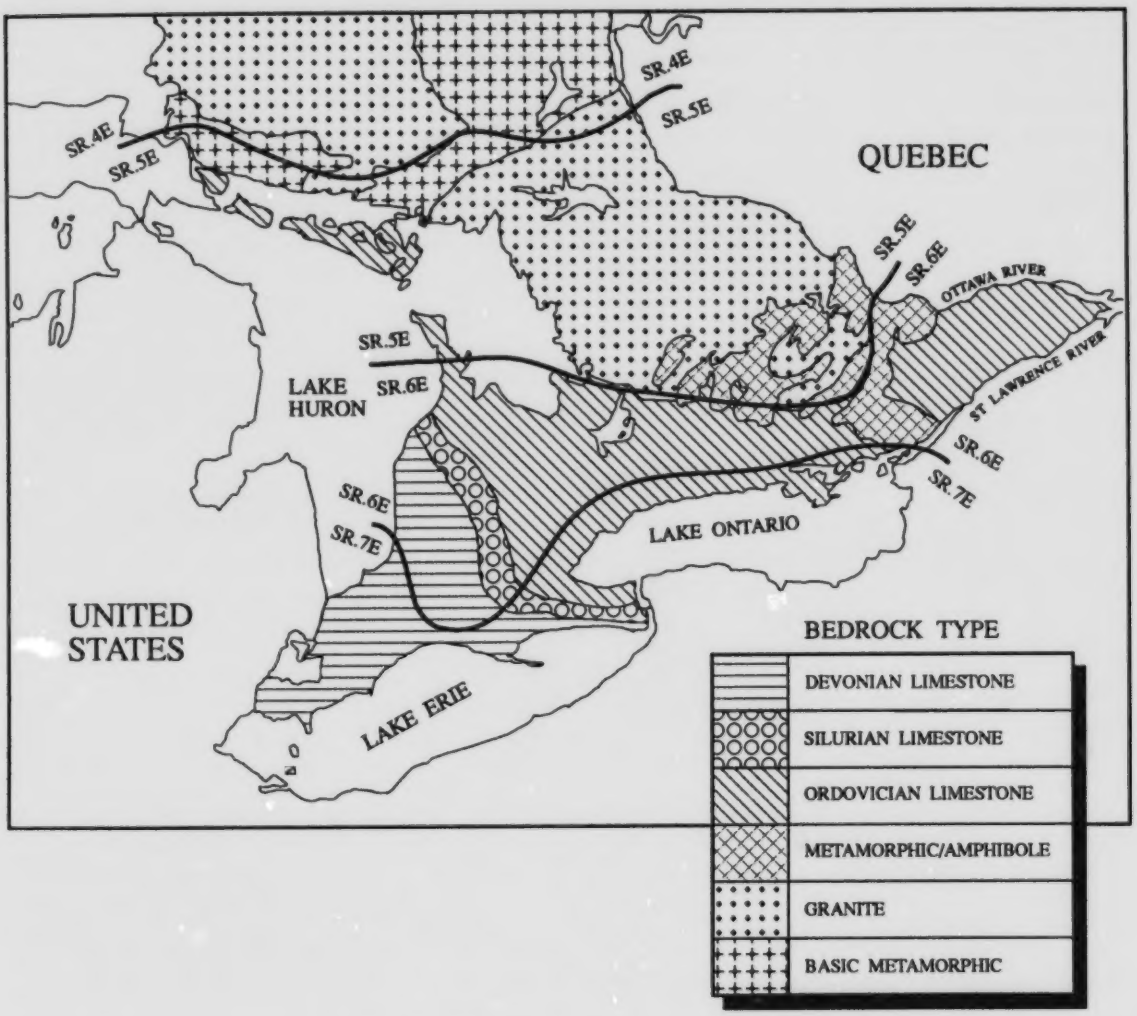
The soils of southern Ontario have developed on a wide range of geological materials and landforms (Taylor 1986). Textural variation of soils is often related to mode of deposition, which in turn is related locally to landform or elevation. For example, upland areas are usually ice-deposited tills (such as moraines), while lower areas are frequently glaciofluvial valley-trains or lacustrine plains of sand or clay. The uniformly fine textured tills bordering the Great Lakes derive much of their silt and clay from these underlying lacustrine beds.

Chapman and Putnam (1984) partitioned southern Ontario into 55 physiographic regions based on landform. Of these regions, 52 occur in the intensively mapped southern Paleozoic portion of the province. They indicate areas of rugged till moraines (Dummer, Horseshoe), drumlin fields (Peterborough), and escarpments (Niagara), separated by undulating till plains and smooth clay and sand plains. Soil textural classes vary from sands (gravels to loamy, very fine sands) through loams (very fine sandy loams to loams) to clays (sandy clay loams to clays). The latter group of classes is usually calcareous and poorly drained (Taylor 1981, 1986).

To the north, on the Precambrian Shield, the soils have been less intensively mapped and are sub-divided into only three areas by Chapman and Putnam (1984). Acid granites and gneisses have weathered to produce coarse-to-medium sands with very low base content. Some tills derived from such materials contain enough silt to be classified as "sandy loam," but with a clay content so low that the term "silty sand" is more definitive. Some "basic" or base-rich Precambrian rocks such as basalt and metamorphic rocks such as amphibolite have base contents higher than granites but still much lower than limestone (see Figure 4); these are considered to be low-base materials (Hills 1960). In the eastern part of this northern zone (near Renfrew), parent materials have been classified and mapped, including their depth-over-bedrock and moisture regimes (Burger 1971).

Over most of the Shield the layer of unconsolidated drift is less than three metres deep, but it is deeper in the moulded till ridges or drumlinoid landforms. Clay deposits within the Precambrian Shield are derived from Paleozoic deposits transported from areas off the Shield.

FIGURE 4: Bedrock geology of southern Ontario (from Chapman and Putnam [1984] and Hills [1959])



Soil profiles are useful in determining the potential productivity of land but must be interpreted locally in combination with relief, soil texture, local climate, vegetation, and management practices. Profile development involves changes in the upper portions of geologic materials of landforms and accumulation of organic residues. This weathered portion is most significant for biological production.

2.2.3 Predominant Site Types

As has already been stated, Ontario can be divided into several physiographic zones according to climate (temperature and moisture) and landform (texture of geologic materials and mode of

deposition). Vegetational succession has been found to follow different patterns in these different areas. In addition, within a given area, successional trends may vary with type of disturbance, such as fire, wind, insects, logging, or land clearing.

The forest sites of Ontario have been variously described (using biotic and abiotic components), classified (in a comparative framework giving ranges of values), and evaluated (to provide production parameters) (Pierpoint 1986). This has given rise to the concept of "site region" (Hills 1959), defined as a part of the land surface within which the response of vegetation to the features of landform follows a consistent pattern (Figure 5). Differences in such relationships among site regions are a reflection of the effect of regional macroclimate. Within a site region, therefore, specific plant successions occur on specific landform positions. It can be considered a region of potential biological production, suggesting probable responses to specific forest practices.

The site region boundaries have recently been updated by Burger and Shidong (1988), and currently agree with the *Ecoclimatic Regions of Canada* being developed by Zoltai (1986).

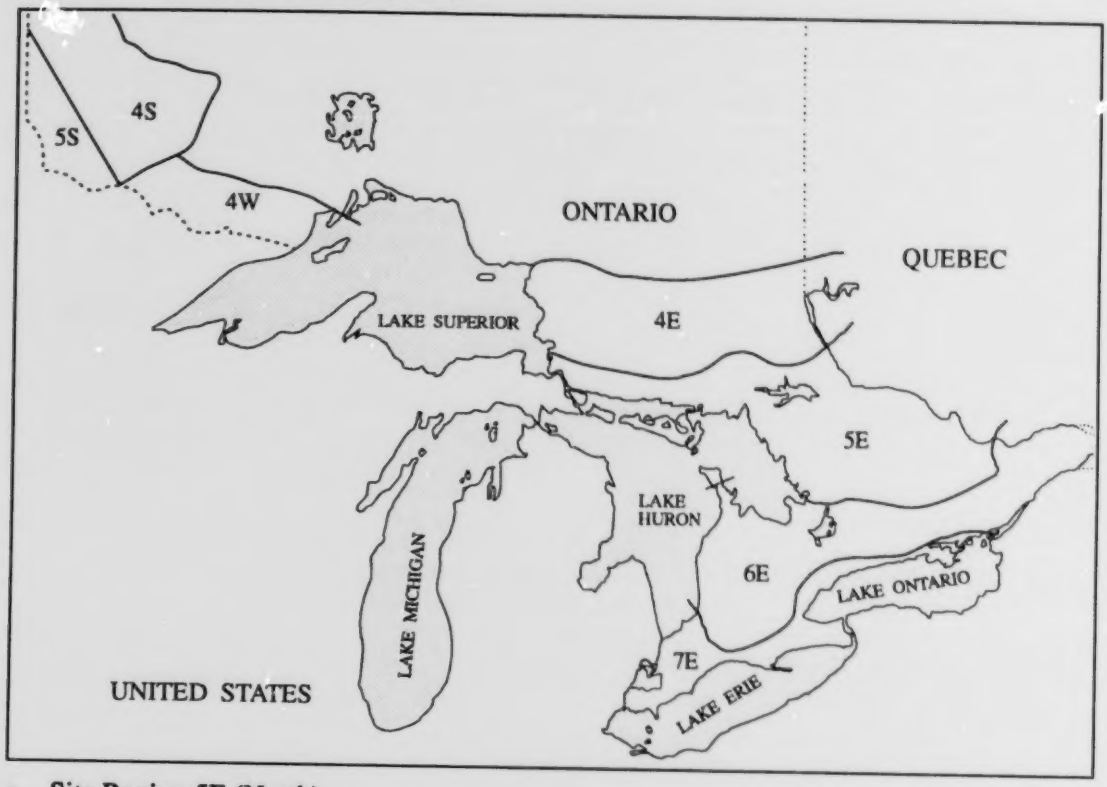
The patterns of stable forests associated with tolerant hardwoods (Site Regions 4E, 5E, 6E, and 7E) are shown in Table 2, according to soil moisture regime (drier, fresh, wetter) and ecoclimate regime (hotter, normal, colder) (Hills 1959). It can be noted that while a hard maple-yellow birch mixture is stable on normal sites in Site Region 5E, it occupies hotter-fresh sites in Site Region 4E. Similarly, yellow birch is replaced by beech on fresh-normal sites in Site Region 6E.

Detailed information on site productivity related to the THWG has historically developed on a region-by-region basis using methods developed according to local need as follows:

- Site Regions 6E and 7E:
  The Ontario Institute of Pedology has developed a system for OMNR to evaluate, by means of site index, the species-suitability for and relative productivity of certain soils (Taylor and Jones 1986). This procedure capitalizes on the Ontario Soil Survey database (Pierpoint and Uhlig 1985), and uses stratified sampling by site region, stand composition, and taxonomic soil series map units. Site index classes are given for each soil series and surface texture class for 16 species, including hard maple, white ash, red oak, black cherry, and beech. To assist with site-specific forest management field decisions, a matrix of soil texture group and depth-to-mottling is used to indicate site class and site index for each species. The information is relevant to even-aged stands only.

- Site Region 5E (South):
  In the southern portion of Site Region 5E, site evaluation has concentrated on recognition of physiographic features and a comparative (subjective) ranking of their productivity. Intensive application of the Hills system has been carried out in local areas such as the University of Toronto Forest near Dorset (Hills and Brown 1955). Using physiographic parameters, Williams (1965) rated sites for potential timber-quality production, indicating maximum relative development for a range of species under "best known" conditions on a variety of landtypes. A forest ecosystem classification for this area is currently being developed.

FIGURE 5: Site regions of Ontario that support species of the tolerant hardwoods working group (from Hills [1959])



- Site Region 5E (North):
  The northern portion of Site Region 5E approaches the commercial limit of the range of tolerant hardwoods. Here, the performance of the group becomes very sensitive to local variations in site. For this reason, the Northeastern Region has developed a detailed Forest Land Productivity Survey (FLaPS) database in which landforms are mapped and described in terms of key soil and terrain components (Heikurinen and Kershaw 1986a, 1986b). The Prime Site Management (PRISMa) Strategy incorporates Forest Soil Mapping (FSM) Units and Forest Resources Inventory (FRI), and includes an economic analysis (Teskey 1986) that is used to select forest sites suitable for "intensive" investment in silviculture (i.e., Prime Lands).

Predominant site types amenable to management for high-quality products in the THWG include:

- a "fractured" site complex of relatively shallow ablation moraine till, often characterized by repeating sequences of ridge-and-valley terrain, with dry ridges, wet valleys, and fresh-to-moist slopes influenced by a telluric water table. Middle and lower slopes are biologically productive but difficult to manage because of terrain configuration.

- a drumlinized landscape in which relatively deep-soiled moulded till ridges, shallowly capped with ablation till, occur sporadically within the fractured site complex. The elevated

TABLE 2: Characteristic Forest Species Commonly Occurring Under Least Disturbed Conditions in Ontario (from Hills [1959])

Physiographic Site Class		Site Region			
		4E	5E	6E	7E
Eco-climate	Moisture Regime	Forest Species Commonly Occurring			
Hotter	Drier	w, r, j Pine - w Birch - t, lt Poplar	**r Oak - w, r Pine (bur Oak)**	a Beech - e Hemlock r Oak - s, r Elm (lt, t Poplar, Juniper)	b, r, sc, sw Oak - Chestnut - p, sb Hickory - Butternut w Pine (Juniper)
Hotter	Fresh	*h,r Maple - y Birch w Pine - b Fir - w Spruce*	*h Maple - r Oak a Beech - e Hemlock*	w, r Oak - sb Hickory (r Elm, Butternut)	Tulip - Walnut - w, r Oak - mn, pn Hickory blue,w Ash, Butternut
Hotter	Wetter	*y Birch - w Cedar (a Elm)*	*a Elm - b Ash - r Maple w(r) Spruce - e Hemlock*	*h, s, r Maple - y Birch - Walnut - b Cherry*	*Sycamore - Tulip a, s Elm - Ash - y Birch*
Normal	Drier	**w, r, j Pine (h,r Maple)**	**w, r Pine - e Hemlock (a Beech, w Ash)**	**h, r Maple - w, r Oak - w Ash - a Elm**	r, w Oak - sb, pn Hickory a, r Elm (Juniper)
Normal	Fresh	**b Fir - w Spruce - w(r) Pine (w Birch - t Poplar)**	**h Maple - y Birch e Hemlock - w Pine (w Spruce - b Fir)**	**a Beech - h Maple - r Oak - e Hemlock**	**h Maple - a Beech - w, r Oak - sb Hickory**
Normal	Wetter	*b Fir - w, b Spruce*	b Ash - r Maple w Pine - w Spruce - b Fir	Hemlock - y Birch a, s Elm, w Cedar, b Fir	**sw, p Oak - r, g, b Ash - s, a Elm - b Hickory**
Colder	Drier	*b Fir - w Cedar*	*w Spruce - b Fir - w Pine*	w(r) Pine w Ash - a, r Elm (w Cedar)	*e Hemlock - a Beech - y Birch - w Pine*
Colder	Fresh	**b Spruce - a Larch**	*b Fir - w Spruce - w Pine (w Cedar, w Birch)*	*w Spruce - b Fir*	**a, s Elm - b Ash - sw Oak - r Maple**
Colder	Wetter	*(locally open) b Spruce - a Larch*	b Fir - b(w) Spruce - a Larch	*b Fir - b, w Spruce a Larch*	*b,w Spruce - b Fir s, r Maple - y Birch*

Species characteristic of regional forests are hyphenated (e.g., r Oak - s, r Elm). Additional species are characteristic of specific sites. Abbreviations for species are shown in Appendix 1.
Parentheses indicate associations and species that are common but are not indicators for all components of the site class. Proportionate distribution of site class with each region: **High**, Moderate, *Low*

plateaus are characterized by fresh-to-moist soils containing water-retentive compacted layers. Frequently covered by pure hardwoods, such sites offer good management opportunities because of flat but productive land.

- lacustrine plains of waterlaid fine sands, silts, and clays, often with fresh-to-moist moisture regimes, and frequently dominated by mixed forest cover. Productivity is often related to depth-to-mottling in the soil. Imperfectly drained sites are usually not suitable due to restricted rooting volume.

Suitable sites for hardwood management have the following soil characteristics:

- Moisture:
  Best conditions are moderately fresh to moist, with hard maple, beech, and red oak occupying fresh (moisture regime [MR] 1-3) while yellow birch and hemlock do well in moist (MR 4-5) conditions. White ash and black cherry occupy a median position. Neither dry nor wet conditions permit high-quality production.

- Texture:
  Silty sands and sandy loams are good, and fine sands and silt loams may be adequate if moisture regime is satisfactory. Coarse sands and heavy clays are not suitable.

- Organic content:
  Well-decomposed and well-incorporated humus materials are required for proper nutrition of hardwoods. Hemlock accumulates raw humus and forms hardpan deposits that are not suitable for hardwoods. Succession to hardwoods may be adversely affected by soil podsolization.

- Chemistry:
  Most hardwood species perform best when soil pH has values in the range of 5.5 to 7.5. More acid conditions will favour hemlock and yellow birch. Strongly acid or alkaline conditions are unfavourable due to effects on nutrient availability or to potential toxic conditions (e.g., soluble aluminum).

- Rooting depth:
  Soils with restricted rooting volume caused by shallow soil deposition or a high water table are unsuitable. An effective depth of at least one metre is required for adequate growth potential. Red oak may persist on shallow ridges and yellow birch may grow on very moist soils (due to rooting character), but neither situation will provide stable timber management opportunities.

Site suitability is also influenced by non-soil factors; the most important one is:

- Microclimate:
  South aspect on slopes may be critically beneficial near the northern transition (i.e., in the Algoma Forest Section) but may limit growth on drier sites elsewhere. Exposed ridges may permit winter sunscald damage to trees, while lower slopes with restricted air drainage may be prone to frost damage.

2.3 Silvics

The silvical characteristics of each species in the THWG define its capacity to reproduce, establish, and develop within the various site types in Ontario. More importantly, they indicate the species' biotic potential to react to and perform following forest disturbance and timber management. Harvesting systems prescribed by proper forest management must harmonize with these features. The methods used for the various species or species groups will differ, each capitalizing on the intrinsic characteristics of the species to optimize forest production, consistent with other forest values.

The following material has been gathered from a wide range of sources, many of which are referenced in other appropriate places in this guide. General overviews of many of these topics are given in Fowells (1965), Treidl (1978), Grisez (1975), Trimble (1975), OMNR (1983), and Myren and Dorworth (1986).

2.3.1 Hard (Sugar) Maple

2.3.1.1 Habitat

- Northern limit parallels the 2° C mean annual isotherm, and growing season can be as short as 30 days in some locations.
- Grows with as little as 500 mm of precipitation if majority occurs during the growing season.
- It is the predominant species in eastern mesophytic late-successional forest and is well adapted to the cool microclimate of mature forests.
- Mature trees are potentially large, growing to 100 cm or more in DBH and 30 m in height, often to ages in excess of 300 years.
- Reproduces aggressively and may occur in pure or mixed, even- or uneven-aged stands on relatively fertile, fresh, well-drained upland sites (MR 1-3).
- In uneven-aged stands, is frequently mixed with beech on fresh sites and yellow birch on moist sites.
- In even-aged stands, is often mixed with less shade-tolerant species such as black cherry, white ash, basswood, and yellow birch.
- In cool areas with more than 760 mm of annual precipitation, may occur on poor, exposed sites, but usually does not thrive there.
- Performs best on sandy loams, loamy sands, and silt loams, often melanized, with pH greater than 5.5 in upper horizons, yet will commonly grow in more acid soils.

- Yield and quality increase as soil fertility improves within suitable moisture regimes (MR 2-3).

2.3.1.2 Reproduction

- Species is monoecious; flowers are either perfect or unisexual, with a male:female ratio of 50:1.
- Flowers appear with unfolding leaves, usually in early May.
- Fruit is a double-winged samara, ripening in twelve weeks and dispersing two weeks later, usually prior to leaf fall.
- Samaras are wind-dispersed effectively for two to three tree-heights and up to 300 m in a strong wind.
- Often one seed-pod of a pair is empty; occasionally both are sterile (a condition known as parthenocarpy).
- Flower crops and seed crops are closely related (and thus predictable).
- Seed production tends to increase with tree diameter.
- Significant seed production begins at about 40 to 60 years of age.
- Mature trees produce some seed most years, with good crops every two to five years.
- Reproduces easily by stump sprouts, and occasionally by root suckers or layerings.
- Sprouting is most vigorous and long-lived in small stumps (less than 15 cm DBH).
- Sprouts usually grow faster than seedlings in first year, often showing a lengthened growing season.
- Seedling sprouts and those from small stumps have the potential to produce high-quality stems if properly tended.

2.3.1.3 Establishment

- Seed has embryo dormancy requiring cold stratification.
- Seed germinates at low temperatures (1°C), often before snow is completely melted in the spring; seed is often covered by litter.

- Germinative capacity is moderate (39 per cent); some seed may be viable into second year.

- Reproduces easily on undisturbed litter because the large seed produces a vigorous radicle, which allows easy penetration of matted leaf layer.

- Species is very tolerant of shade; seedlings can persist for several years under 5 per cent full light and can produce modest growth at 13 per cent full light.

- Early survival of young germinants is enhanced by shade, often resulting in prolific advance growth of small seedlings even under a full overhead canopy.

- Dense seedling populations show high turnover rates under heavy shade (often with 50 per cent mortality in the first three years).

- Older seedlings persist under heavy shade but exhibit slow growth; seedlings 50 cm tall at age 25 years with annual increments as low as 1 cm and saplings 2.5 cm DBH at 50 years of age are not rare.

- Species usually does not reproduce aggressively by seed on abandoned, cleared land.

- Species may reproduce aggressively by seedling sprouts in excessively opened stands (less than 9 m^2/ha of basal area) from seedlings damaged during harvest, producing essentially even-aged regeneration.

2.3.1.4 Development

- Usually leafs-out earlier than associated species, with understory trees preceding those in the overstory.

- Height and radial growth commence with leaf expansion (in early May).

- Height growth is determinate and 85 per cent complete by the end of June (6 weeks) and ceases by early August (15 weeks); radial growth is 80 per cent complete by the end of July (8 weeks) and ceases in late August (14-17 weeks).

- Juvenile height growth averages 30 cm per year under moderate stocking levels and is negligible after 150 years.

- Self-pruning is good with sufficient stocking but little merchantable length is added after trees reach approximately 45 cm DBH.

- Exhibits slow-to-moderate but persistent diameter growth; in unmanaged stands, mature trees may grow an average of 2.5 cm in ten years.

- Shows remarkable response to release (i.e., it is an elastic species) both in height and diameter growth of immature trees; annual height increments of 90 cm and ring widths of 10 mm are possible (but not common).

- Even badly suppressed trees respond well and can show improvement in size and quality when released.

- Excessive release of suppressed trees up to 20 cm DBH often promotes development of epicormic branches from dormant buds; these branches often die within eight years if stand density increases.

- Excessive release may promote sunscald, top decline, and persistent stem forks.

- The root system is relatively deep and branching on well-drained soils, and trees are relatively resistant to windthrow except on thin soils or shallow-capped drumlin landforms.

- Periodicity of root growth is independent of top growth, and occurs in surges throughout the growing season; root grafts are common within the species.

- Unmanaged, uneven-aged forests, even on the best sites, are characterized by great variation in defect and quality.

- Ease of reproduction, shade tolerance, and response to disturbance promote uneven-aged stands and make species amenable to the single-tree selection system of management.

- Even-aged stands may be managed as such or converted to uneven-aged stands as they approach maturity.

2.3.1.5 Damaging Agents

- Decay losses caused by trunk and butt infections are serious in unmanaged stands. In Site Regions 4E and 5E, cull averages 30.4 per cent of gross merchantable volume and ranges from 22 per cent at 33 cm DBH to 40 per cent at 60 cm DBH. Brown stain accounts for 80 per cent of the defect volume. The high defect values at young ages are unique to maple and reflect the slow growth of suppressed trees (Basham and Morawski 1964; Morawski et al. 1958).

- South of the Shield, in Site Region 6E (e.g., Grey County), 65-year-old trees exhibit 5 per cent cull compared to 22 per cent in Site Region 5E. The lower values are associated with faster growth rates and a lower incidence of stain in trees (Basham 1973).

- Annual volume losses caused by decay fungi average almost one million cubic metres per year (916 000 m^3) (see Table 3).

TABLE 3: Estimated Annual Volume Loss (m^3 x 1000) 1977-1981, Caused by Destructive Agents in the THWG in Ontario (from Gross [1985])

Agent	Species	Volume Loss	Mortality	Total Loss
Forest tent caterpillar	hard maple	342	653	995
	yellow birch	4.8		4.8
Oak complex	red oak	7.5	36	43.5
Oak leaf shredder	red oak	5	20	25
Dieback	hard maple		375	375
	red oak		63	63
Decay	yellow birch	282		282
	hard maple	916		916
	ash spp.	28		28
	red oak	66		66
	beech	111		111
	black cherry	4		4
	hemlock	86		86

- *Polyporus glomeratus* Peck[4] accounts for about a third of infections and volume loss and, together with *Armillaria mellea* (Vahl ex Fr.) Kummer and *Pholiota spectabilis* (Fr.) Kummer, represents more than 50 per cent of all cull.

- Parasitic fungi that can kill maples include cankers (e.g., *Eutypella parasitica* Dav. & Lor., *Nectria galligena* Bresad.) and sapstreak disease.

- Defoliation by leaf-feeding insects, primarily forest tent caterpillar, occurs cyclically, and not only reduces growth (341 000 m^3 annually from 1977 to 1981) of the host species, but also depletes food reserves, resulting in mortality in the case of successive infestations (653 000 m^3 mortality annually from 1977 to 1981) (see Table 3).

- Stem quality degrade and tree mortality caused by breakage are associated with attacks by sugar maple borer, from tunnelling activities in the cambial zone during the larval stage.

- Significant cyclical population increases of red-backed vole often result in sapling mortality

[4] Scientific names are used in the text for organisms lacking unique common names. Scientific names given here are widely used operationally, but periodic taxonomic revisions are made as their genetic relationships are clarified. Refer to Myren and Dorworth (1986) concerning disease organisms.

from basal stem girdling. This is often most noticeable in winters characterized by excessive snow depth.

- Man-made damage related to sap-tapping operations and poorly organized stand harvesting and tending procedures reduces the quality of residual stems and serves as infection courts for both volume and value losses (Love et al. 1972).

- Abiotically induced damage includes that associated with climate (frost crack, sunscald, glaze breakage, and bud killing). The results are infection courts for fungi, and damage to the form and potential merchantable length caused by forking.

- Maple decline (characterized by crown dieback, loss of vigour, and frequently death) is of unresolved origin, but is often associated with insect defoliation and climatic stress. Mortality losses from 1977 to 1982 averaged 375 000 m^3 annually (see Table 3).

- Extensive damage to hard maple caused by pear thrips defoliation has recently occurred in the eastern United States.

2.3.2 Beech

2.3.2.1 Habitat

- Northern limit closely parallels the -12°C mean January isotherm; can withstand cold temperatures but is prone to frost crack.

- Is mesophytic, occurring in areas having greater than 635 mm of annual precipitation.

- Can reproduce aggressively in undisturbed upland sites; forms a dominant member of moist late-successional forest communities.

- Occasionally forms pure stands; more often found in uneven-aged mixtures with hard maple, yellow birch, and hemlock.

- A long-lived tree, reported to reach 400 years, but typically not exceeding 250 years due to stem breakage associated with internal decay.

- Commonly grows to 60 cm DBH and 27 m tall.

- Grows best on fertile, well-drained fresh soils, especially loamy soils with high humus incorporation.

- Adapts to poorer, shallow sites if moisture regime is fresh enough (MR 1-2), but vigour and quality usually decline.

2.3.2.2 Reproduction

- Species is monoecious, with unisexual flowers.
- Flowers appear in early May during period of leaf expansion.
- Seed ripens between September and November; burs open to release seed with first heavy frost.
- Large quantities of seed (mast) may be consumed by bears prior to, and deer subsequent to, dispersal.
- Dispersal usually restricted to vicinity of parent (one tree-height distance) because seeds are heavy; may be transported by animals.
- First seeds to fall may be aborted or wormy.
- Dispersal complete within two weeks; empty burs remain on tree overwinter.
- Individual trees are consistent in seed production ability.
- Bears seed adequately starting at 40 to 60 years of age.
- Good seed crops occur every two to three years; light crops occur in intervening years.
- Sprouts well from stumps up to 10 cm in diameter; sprouts from larger stumps are often short-lived.
- Dense thickets of root suckers may surround older trees; few develop into good trees due to lack of independent root system.
- Can occasionally reproduce by layering.

2.3.2.3 Establishment

- Seed exhibits embryo dormancy requiring cold stratification; germinates best at approximately 15° C; no delayed germination.
- Germinative capacity is usually high (for sound seed), but seed is susceptible to drying.
- Species has no difficulty establishing itself on undisturbed hardwood litter because of high vigour of germinant radicle.

- Requires adequate moisture in soil or organic layer, but germinates poorly on excessively wet sites.

- Very shade-tolerant, though apparently less so on poorer sites; can grow moderately well in 13 per cent full light.

- Seedlings develop better beneath a moderate canopy or in a small protected opening than in full light or clearcuts, probably because of drying effect of exposure on soil.

- May form dense seedling stands under full shade because of its shade tolerance and relative freedom from deer browsing.

- Usually overtopped by associates and intolerant species in conditions of low stocking.

- Often performs better on north aspects (which promote moisture conservation).

2.3.2.4 Development

- Radial growth begins with full expansion of leaves and continues until late August, depending strongly on soil moisture availability; diameter growth is usually completed in 15 weeks.

- Height growth is determinate and is 90 per cent complete by the end of June; shoot tips may abort after extension of preformed leaves.

- Saplings can withstand intensive shading and recover when released (i.e., species is elastic); severely suppressed trees are often flat-topped and crooked.

- Rated slow in relative DBH growth rate; often averages 2.5 cm in ten years for mature trees in fully stocked stands, and double that rate in "partially cut" stands.

- Natural pruning is adequate in well-stocked stands.

- Prone to sunscald and epicormic branching after exposure caused by heavy cutting (greater than 50 per cent basal area removed), especially in trees less than 10 cm DBH.

- Root system is wide-spreading and moderately deep; often remains shallow where soil moisture is adequate; species is relatively windfirm.

- Root grafting is common; root suckers are common in overmature specimens.

- Bark is thin and vulnerable to fire, frost, bear, and mechanical injury.

- Shade tolerance and ease of establishment make this species suitable for uneven-aged management systems.

2.3.2.5 Damaging Agents

- Potentially the most damaging (lethal) agent is the beech bark disease complex, initiated by primary feeding-injury from the beech scale, followed by secondary infection by *Nectria coccinea* var. *faginata* Lohm, Wats, and Ay. This disease is not yet widespread in Ontario but has caused much deterioration of beech in the United States.

- Beech is a defective species in terms of decay, but less so than hard maple at immature stages, and less so than yellow birch at all stages of maturity. Two-thirds of defect in beech involves brown stain (Basham and Morawski 1964).

- Of the remaining defect, about 16 per cent is caused by white spongy rot and 14 per cent caused by yellow-brown stringy rot.

- *Polyporus glomeratus* (a yellow-brown stringy rot) causes 36 per cent of all decay infections and, together with *Fomes igniarius* (L. ex Fr.) Kickx (a white spongy trunk rot), *Pholiota adiposa* (Fr.) Kummer, and *Armillaria mellea* (yellow-brown stringy trunk and butt rot), constitutes 66 per cent of all infections and decay (Basham and Morawski 1964). Average cull in sawlogs in the Algonquin Ecological Section is estimated to be 35 per cent (Morawski et al. 1958).

- Annual volume losses in beech caused by decay fungi have averaged 111 000 m^3 per year from 1977 to 1981 (see Table 3).

- Beech is infected by canker diseases caused by *Strumella* spp. and *Nectria galligena*.

- Beech foliage is favoured food for saddled prominent and may be part of the host preference of Bruce spanworm.

- Species is thin-barked and very susceptible to injury from logging, fire, sunscald, and animal feeding.

- Bark is consumed as food by beaver, bear, squirrel, porcupine, and vole.

- Subject to frost crack, often related to an internal wetwood condition; may be killed by severe cold following a period of drought.

- Seeds are consumed in quantity by black bear, deer, and various birds and rodents; this may affect regeneration potential.

2.3.3 Yellow Birch

2.3.3.1 Habitat

- Occurs south of the mean July 16° C isotherm in areas with an effective growing season longer than 160 days.
- Extends north to the mean January -15° C isotherm west of the Great Lakes, but only to the mean January -12° C isotherm in the east.
- A prominent member of the successional forests of eastern North America.
- Develop as potentially large trees, 100 cm or more DBH and 30 m in height, often reaching ages in excess of 300 years.
- A successional species; tends to be replaced by more shade-tolerant species (e.g., hard maple, beech) with time, due to lack of regenerative capacity in undisturbed stands.
- Occurs in almost pure even-aged stands (of fire origin), and mixed with hardwoods on uplands and with hemlock around lakes.
- Most productive on moist lower slopes (MR 3-5) with deep loamy soils and moving (telluric) water table; more tolerant of poor drainage than hard maple.
- Usually replaced by beech in association with hard maple on dry-to-fresh sites.

2.3.3.2 Reproduction

- Species is monoecious, with unisexual flowers (catkins).
- Cone-like female catkins emerge with leaves in spring; late frosts may abort the seed crop.
- Seed ripens in September/October; dispersal begins after leaf fall, with the onset of cold weather, and continues through early winter (November-February); conelets slowly disintegrate during dispersal.
- Wind dispersal of seed occurs up to one kilometre on snow crust; more commonly, extends two to four tree-heights.
- Seed with highest viability tends to fall earliest and in closest proximity to parent tree (tends to be heavier); low viability often associated with poor seed year.

- Seed is occasionally sterile (parthenocarpy).
- Seed production begins at 40 years (about 12 cm DBH), although fruiting has been observed on 9-year-old trees.
- Most abundant seed production occurs after 70 years (when trees are more than 20 cm DBH).
- Good seed crops occur every three years (allowing three crops in ten years); can be forecast by presence of male catkins on twigs in previous winter; bumper crops occur at ten-year intervals.
- Can form sprouts from seedlings or small stumps, but such sprouts are usually of low vigour; no root suckers form.

2.3.3.3 Establishment

- Seed exhibits embryo dormancy requiring cold stratification; seed germinates best at a higher temperature threshold (16° C) than hard maple, slightly delaying establishment.
- Germinative capacity is variable (30 to 60 per cent), usually higher in a good seed year; viable seed rarely lasts until second year.
- Does not establish on undisturbed hard maple litter because the small germinant radicle is not strong enough to penetrate matted maple litter.
- May become established in hemlock litter or birch litter that shows curl-drying effect; often reproduces on rotting fallen stems or stumps, producing stilt-rooted or "perched" birch.
- Humus or moist mineral soil exposed by logging, fire, or windthrow provides a good medium for germination; best survival and growth requires some organic material (humus mixed with mineral soil).
- Considered intermediate in shade tolerance (between black cherry and hard maple).
- Establishment requires some partial shade (40 per cent canopy); adequate moisture and moderate soil temperature are required for survival.
- Seedlings must attain heights of 15 cm in the first year to prevent smothering by subsequent maple/beech leaf fall.
- Once established, seedlings need overhead light to grow adequately relative to tolerant competition.
- Often successfully regenerates and competes in small openings of 0.1 ha or less; in larger openings, birch is often confined to edges or borders of a patch.

2.3.3.4 Development

- Height growth is indeterminate, beginning about mid-May and at times continuing until fall frost (early September); shoot tip of last of successional growth flushes usually aborts.
- Given adequate light (e.g., basal area less than 9 m^2/ha), yellow birch will grow faster in height than either hard maple or beech.
- Response of height development is inversely proportional to overstory stocking level for the first 20 years; internode lengths of 75 cm per year may be expected at basal area levels of 6 m^2/ha.
- Diameter growth rate is moderately low; crown size is often smaller than hard maple for trees of similar size.
- Relatively inelastic; it does not respond to release from severe suppression, and responds only moderately to release from light suppression.
- Prunes well when adequate regeneration stocking is attained.
- Develops a shallow, wide-spreading (plate-type) root system; trees are subject to windthrow on thin or saturated soils.
- Decline symptoms, post-logging decadence, and profuse epicormic branching often occur on residuals in excessively opened stands.
- Initial requirement for partial shade and seedbed preparation followed by gradual release suggests shelterwood as a form of even-aged management, or group selection if managed with uneven-aged maple.

2.3.3.5 Damaging Agents

- Yellow birch is one of the most defective of the valuable hardwoods in Ontario, particularly in trees greater than 100 years of age, averaging 42.3 per cent cull in Site Regions 4E and 5E.
- Annual volume losses from decay in yellow birch were estimated to be 282 000 m^3 per year from 1977 to 1981 (see Table 3).
- Brown stain accounts for 70 per cent of the defect; of the remaining defect, 15 per cent is caused by yellow-brown stringy rot,followed by white spongy rot and incipient yellow rot.
- Forty per cent of decay infections are caused by *Stereum murraii* (Berk. & Curt.) Burt (yellow-brown stringy trunk rot), which together with *Pholiota adiposa* (yellow-brown stringy trunk and butt rot) and *Fomes igniarius* (white spongy trunk and butt rot) constitutes nearly 70 per cent of all decay infections (Basham and Morawski 1964).

- Cull volumes increase consistently with tree size and were found to be higher in Algoma than in Algonquin Ecological Section (Morawski et al. 1958), perhaps due to slower growth and greater ages in Algoma.

- Cankers caused by cyclical infections of *Diaporthe (Phomopsis) alleghaniensis* Arnold periodically kill regeneration and small saplings. Target cankers caused by *Nectria galligena* occasionally girdle large saplings.

- Birch leaf miner and birch leaf skeletonizer cause reductions in effective leaf area and subsequent reductions in growth; gypsy moth includes yellow birch in its food source.

- Forest tent caterpillar causes defoliation, and is estimated to have reduced volume growth by 4800 m^3 annually in the period 1977 to 1981 (see Table 3).

- Trees weakened by stress may be attacked by bronze birch borer, often resulting in mortality.

- Birch dieback, a disease of unknown origin, caused considerable growth reduction and tree mortality in the 1950s; deterioration of residual trees (post-logging decadence) is common in stands that have been excessively cut over.

- Stem girdling from repetitive seasonal drilling by yellow-bellied sapsucker can cause top-dying and mortality of trees of all sizes.

- Bark and branch stripping by porcupine may cause severe reduction in growth, poor form development, and death from eventual suppression.

- Yellow birch is a favoured browse species of white-tailed deer and also is extensively clipped by hare in years of peak population.

2.3.4 Eastern Hemlock

2.3.4.1 Habitat

- Restricted to cool, humid climate with January means above -12° C and July means below 18° C.

- Northern limit near Lake Superior coincides with a mean of 1167° C growing degree-days during frost-free season.

- Occurs where frost-free season is as short as 80 days, but species may be damaged by spring frosts.

- In the coolest part of its range, requires more than 760 mm of precipitation annually; it must have available moisture in all seasons.

- A long-lived species: mature trees frequently grow in excess of 250 years; individuals are known that are more than 500 years old.

- Old trees attain large sizes, commonly 75 cm DBH or more and 24 m tall.

- A component of late-successional ("climax") forests; forms pure stands or associates with hard maple and beech on favourable upland sites (MR 1-2) or with yellow birch around lakes (MR 4-5).

- Even-aged stands are unusual, although stands of uniform-sized trees occur.

- Adaptable to many sites but most abundant on north aspects.

- Acid litter associated with thick organic layer and podsolization, often with iron hardpan in subsoil; organic layer thickness tends to be proportional to overstory hemlock stocking density.

- Once established, competitive ability over the long term (300 years) is usually better than associated species.

2.3.4.2 Reproduction

- Trees are monoecious, with imperfect flowers; male and female flowers are borne on different branches of the same tree.

- Flowers appear in mid-May; fruit ripens in September and October.

- Small winged seeds are shed during fall and winter, often onto snow pack; seedfall is intermittent, with cones open only during dry weather.

- Seed is wind-dispersed, up to one kilometre on snow crust; empty cones remain on tree into following year.

- Open-grown trees fruit when 20 to 40 years old; those under moderate shade do so at 30 to 50 years.

- Suppressed trees, (i.e., those growing under a dense canopy) may never fruit regardless of age; mature dominants may produce cones at ages in excess of 400 years.

- A prolific seeder, with crops every two to three years in mature stands.

- Does not sprout; layering is rare.

2.3.4.3 Establishment

- Seed exhibits dormancy requiring cold stratification; germinative capacity is low (30 per cent), with seed viability of one year.
- Optimum germination occurs at 15° C.
- Does not reproduce well on undisturbed seedbed characterized by thick, dry organic layer or matted maple litter due to fragility of germinant.
- Favourable seedbeds include moist, well-decomposed litter, rotted wood, and moss mats on soil or rocks; mixed mineral and organic soil is best medium for survival and growth.
- Early survival depends on availability of moisture in upper soil layers and on adequate light.
- Very shade-tolerant; seedlings can grow adequately enough to survive in less than 20 per cent full light; moisture is more critical than light for survival except in densest shade.
- Establishment is better in partial shade (at least 75 per cent full canopy) than in full light, especially on dark-coloured organic seedbeds (due to heat injury, desiccation).
- Seedling height development is slow in the first year (2-5 cm); seedlings may be smothered by subsequent hard maple leaf fall (hemlock, birch, or beech leaf fall is less critical).
- Older seedlings can tolerate dense shade (five per cent full light) but grow slowly; they can also tolerate more exposure to strong light.

2.3.4.4 Development

- Height growth begins in mid-May and continues until late August; 90 per cent of height growth is completed in 90 days.
- Vigorous saplings in light or medium shade may grow 20 to 30 cm annually in height and approach 45 cm per year in full light providing adequate soil moisture is available.
- Saplings grown in deep shade may be only 2.5 cm DBH at 100 years of age.
- Understory saplings show variable response to release but may grow as much as 10 cm in DBH per decade.
- Release response is proportional to active crown size; trees with full crowns respond in the first year, while those with live crown ratios of less than 50 per cent are delayed.

- Better response of hemlock associated with hardwoods reflects better crown development; trees may respond to release even at advanced ages (greater than 200 years).

- Because of shade tolerance, crowns are often deep, associated with slow natural pruning and excessive taper.

- Shallow-rooted and subject to windthrow and fire damage; may form root grafts.

- Extremely sensitive to sudden changes in stand density; soil drying and attacks on weakened trees by wood borers may lead to mortality, especially of mature trees.

- Harvesting method must leave relatively high hemlock stocking levels (16 m^2/ha) to ensure an adequate seed source, shade, and moisture for reproduction and early development.

- Selection method or a three-cut uniform shelterwood with seedbed preparation is the most effective means of management in either uneven-aged or even-aged systems.

2.3.4.5 Damaging Agents

- Has a relatively low incidence of defect caused by decay fungi, and shows a very gradual increase in cull with age. Average cull for sawlog material is 20 per cent (Morawski et al. 1958).

- Annual volume losses from decay have been estimated to be 86 000 m^3 per year from 1977 to 1981 (see Table 3).

- *Stereum sanguinolentum* (Alb. & Schw. ex Fr.) Fr. (red heart rot) accounts for 54 per cent of decay infections and, together with *Corticium galactinum* (Fr.) Burt (yellow stringy butt rot) and *Pholiota adiposa* (yellow stringy rot), constitutes 70 per cent of all decay infections (Basham and Morawski 1964).

- An alternate host for a variety of leaf rusts.

- Hemlock looper is a periodic defoliator; hemlock borer is a non-aggressive flat-headed borer that attacks trees weakened by stress.

- Ring shake, often associated with drillings of the yellow-bellied sapsucker and aggravated by wind action (following harvest of a fully stocked stand) and various growth stresses, contributes to the average 20 per cent cull factor exhibited by this species.

- Suffers severely from post-logging decadence associated with excessive cutting practices apparently caused by sudden soil desiccation.

- Browsed by white-tailed deer and may be debarked by porcupine.

2.3.5 Red Oak

2.3.5.1 Habitat

- Occurs in areas with mean annual temperatures above 4°C; requires 1333°C growing degree-days per year.
- Occurs in areas with mean annual precipitation ranging from 500 to 1500 mm, but grows best on sites that are fresh throughout the year.
- Often occurs on dry sites, but these usually have a north or east aspect that is cooler than average for the area.
- Usually a minor component of successional stands.
- Trees commonly grow to be 20 to 25 m tall, and 30 to 90 cm DBH but may exceed 30 m and 120 cm, respectively, under ideal conditions.
- Best growth occurs on fresh-to-moist, well-drained soils in coves and mid/lower slopes; toward its northern limit, red oak may form pure stands on rocky ridge crests.
- Best sites are characterized by fresh, loamy soils (MR 2-4), but species may reproduce more easily and be found more frequently on drier, coarser-textured sites (MR 0-1).
- Aspect and slope appear to be important factors affecting stem quality.

2.3.5.2 Reproduction

- Species is monoecious; male and female flowers develop with leaves in late April or early May.
- Acorns require 18 months to mature; they ripen in September and October of the year following fertilization.
- Acorns are dispersed by gravity in September through November falling near parent tree.
- Squirrels or mice consume or transport and cache significant quantities of seed; caches may constitute important colonization opportunities for species.
- Acorns are also an important food for deer.
- Acorn production begins at 20 to 30 years of age; optimum yields are attained at 50 to 75 years (yields are poor after age 250 years).

- Acorn production increases with DBH up to 60 cm; crown size is important.
- Dominant trees produce most seeds; south and west sides of crowns produce more acorns per unit area.
- Seed production is related to stand density; site quality affects only acorn weight.
- Individual trees show consistent seed production characteristics; good seed crops occur every two to ten years, with complete failures in some years.
- Reproduces easily by stump sprouting; small stumps sprout more frequently than large stumps.
- Stems of seedling-sprout origin are as good as seedlings and can develop into thriving trees.
- Sprouts originating at root collar or below ground develop less decay because of an independent root system.

2.3.5.3 Establishment

- Seed exhibits dormancy requiring cold stratification; seeds remain viable for only one winter.
- Ideal seedbed for acorns is moist, well-drained mineral soil; seed germination is best when buried two centimetres in soil with light litter cover.
- Oak seedlings are more numerous where mineral soil has been disturbed (e.g., by fire or logging).
- Germination is followed by vigorous, rapid tap-root development.
- Adequate regeneration occurs only in years of high seed production due to serious seed predation (by squirrels and birds), and insect damage (which results in wormy acorns).
- Shade tolerance is intermediate (less than hard maple but more than black cherry).
- Survives only a few years under dense canopy; may survive several years under moderate canopy, but top usually dies and resprouts.
- Once established, requires full light for survival and growth; makes more rapid height growth under such conditions than its more tolerant associates.

2.3.5.4 Development

- Height growth is determinate and is 90 per cent complete in 40 days.
- Species asserts dominance at an early age by rapid expansion of crown.
- Relative diameter growth is usually greater than that of common hardwood associates; trees often average one centimetre per year of diameter growth.
- Productivity is greatly influenced and determined by soil moisture.
- Responds well to release from moderate suppression; sapling and pole-sized dominants or codominants respond best.
- Susceptible to epicormic branching following heavy release; dominant and codominants develop fewer sprouts than suppressed trees and there is less serious development in older trees.
- Forest-grown trees show good self-pruning; trees often have straight trunks free of branches for 50 per cent of height.
- Root system is deep and spreading, and may include a tap root; may form root grafts with companion oaks.
- Group selection or shelterwood systems are recommended for even-aged management, depending on stand composition and management objectives (group selection using small openings will require frequent tending).

2.3.5.5 Damaging Agents

- Although relatively decay-resistant, annual volume losses from decay have been estimated to be 66 000 m^3 per year from 1977 to 1981 (see Table 3). Studies in the United States have estimated that cull averages 19 per cent in oaks (Baxter 1943).
- In American studies, the most important white trunk rot infecting red oak is *Polyporus compactus* Overh., which accounts for 36 per cent of infections and, together with *Stereum frustulatum* (Pers. ex Fr.) Fckl., *Stereum gausapatum* (Fr.) Fr., and *Inonotus (Poria) Andersonii* (Ell. & Ev.) Cerny, constitutes 80 per cent of all trunk rot infections. The major brown butt rot is *Laetiporus (Polyporus) sulphureus* (Bull. ex Fr.) Bond. & Sing., which accounts for 33 per cent of infections (Berry and Lombard 1978).
- A major insect problem is the oak leaf shredder; it has caused an estimated annual volume loss of 5000 m^3 per year and mortality of 20 000 m^3 per year in (see Table 3).

- Oak decline complex is a stress-related dieback condition that is closely associated with the oak leaf shredder. This complex has resulted in an estimated average annual volume loss of 7500 m^3 and mortality amounting to 36 000 m^3 per year (see Table 3). *Armillaria mellea* (shoestring root rot) may be involved in aggravating the condition.

- A favoured food for gypsy moth, which can lead to mortality following successive years of defoliation. Infestations of oak skeletonizer can cause severe defoliation.

- Stem borers causing degrade of wood products are the Columbian timber beetle, carpenterworm, and red oak borer. Galleries created by these pests may become infected with decay fungi.

- Acorn weevils can cause serious losses in seed viability in epidemic years.

- *Strumella coryneoides* Sacc. & Wint. causes a severe, girdling canker on oak, similar in appearance to that associated with *Eutypella* on maple. Canker and dieback of oak can also be caused by *Dothiorella quercina* (Cooke & Ell.) Sacc.

- A potentially lethal vascular disease known as oak wilt, common in the U.S. Lake States but as yet undetected in Canada, may threaten the oak resource in the future. It is spread by an insect vector, usually *Nutidulid* sap-feeding beetles.

- Deterioration has been associated with weakening by glaze damage with subsequent infection by *Armillaria mellea.*

2.3.6 White Ash

2.3.6.1 Habitat

- Grows where the mean January temperature is greater than -12° C.

- Restricted to areas with a growing season in excess of 180 days and 1333° C growing degree-days.

- Requires 760 mm or more of annual precipitation.

- A minor but frequent component of the eastern mesophytic forest; characteristic of early and intermediate stages of natural plant succession.

- Trees are commonly 20 to 25 m tall with diameters of 45 to 60 cm; occasionally trees may be 30 m tall and 90 cm in diameter.

- Demands substantial soil fertility and moisture; grows best on fresh-to-moist, well-drained sites (MR 2-4) with sufficient nitrogen and calcium.

- Common on luvisols and brunisols with pH greater than 5; grows well in soils underlain by compacted till supporting a telluric water table.

- Considered a soil-improving species.

2.3.6.2 Reproduction

- Species is dioecious; male trees flower heavily most years while female trees flower only two to three years out of every five years.

- Flowers bloom before leaf buds enlarge; pollination is confined to a very local area and requires 10 to 15 trees per hectare for seed production.

- Fruit (samara) ripens in mid-August/October; seeds are wind-dispersed up to 150 m or two to three tree-heights in early winter.

- Good seed crops are produced every three to five years.

- Flowering may commence when trees are 8 to 10 cm DBH but more commonly begins at 20 to 25 cm DBH.

- Minimum age of seed production is 20 years; maximum age is 175 years.

- Spring flower crops are a good predictor of seed crops.

- Seed production is inversely related to stand density.

- Stumps of freshly cut seedlings and saplings sprout readily and grow rapidly.

2.3.6.3 Establishment

- Seed exhibits embryo dormancy requiring two to three months of moist, cool stratification.

- Field germination is relatively low; many seeds rot over winter.

- Shows delayed germination, with up to 75 per cent germinating in the second spring; seed may remain viable for three years.

- Minimum seedbed requirement is light litter; may seed-in readily on fertile abandoned fields.

- Shade tolerance is intermediate; shade-enduring when young; can establish in 3 per cent full light, but best growth occurs in 45 per cent full light.

- Often more commonly present in the understory than the overstory; may require 3 to 15 years to grow to breast height.

- With increasing age, becomes more intolerant of shade.

- Sprouts often grow faster than seedlings (40 cm per year).

2.3.6.4 Development

- Shows determinate shoot-growth pattern; height growth is 90 per cent complete in the first 30 days and 100 per cent complete in 60 days.

- Post-juvenile growth rates are relatively fast; may attain 10 cm DBH and 11 m in height by age 20 years, and 30 cm DBH and 23 m in height at 50 years.

- Dominant and codominant trees show good response to thinning or release; species shows good positive correlation between basal area growth and crown diameter.

- Shows strong apical dominance and low susceptibility to epicormic branching.

- Self-pruning is well-developed; branches fall two to five years after death; clear lengths in excess of 40 per cent of height are possible in trees 30 m tall.

- Live-pruned branch scars heal very quickly.

- May be successfully reproduced by a variety of management systems.

2.3.6.5 Damaging Agents

- Decay is not a severe problem and has not been investigated thoroughly in Ontario. In the United States, estimates of eight per cent cull have been noted by Baxter (1943).

- Annual volume losses in Ontario have been estimated to be 28 000 m^3 per year over the period from 1977 to 1981 (see Table 3).

- White mottled rot (*Fomes fraxinophilus* [Pk.] Sacc.), white rot (*Polyporus gilvus* [Schw.] Fr.), and spongy white rot (*Polyporus hispidus* [Bull.] Fr.) are specific to ash.

- Canker and branch mortality are caused by *Cytospora (Valsa) pruinosa* (Fr.) Hohnel.

- Leaf diseases causing crown thinning and defoliation are caused by ash leaf spot, ash leaf rust, and anthracnose.

- Insects causing leaf destruction and defoliation include fall webworm and ash sawfly.
- Boring insects that degrade xylem tissue and create infection courts for fungi include ash borer and carpenterworm.
- The ash flower gall mite causes abortion of male flowers.
- Ash dieback or decline occurs cyclically and is of unspecified origin. Chlorosis and dieback of ash has been associated with a mycoplasma (ash yellows), as well as with tobacco ring spot virus and tobacco mosaic virus. *Armillaria mellea* has also been associated with stress-related ash dieback conditions.

2.3.7 Black Cherry

2.3.7.1 Habitat

- Requires cool, moist sites but seldom occurs north of the 5° C mean annual isotherm.
- Species is neither resistant to high temperature nor extremely frost-hardy.
- A minor component of the eastern mesophytic hardwood forest.
- Commonly 20 to 25 m tall with DBH of 45 to 60 cm; may reach 30 m in height in its southern range and may develop poor form (sweep) toward its northern limit.
- Seldom exceeds 200 years of age.
- Grows best on moist (MR 3-4), rich, well-drained loamy soils; lower slopes and coves are often suitable.
- Often occurs on north- and east-facing slopes; dry ridges provide unfavourable growing conditions.

2.3.7.2 Reproduction

- Species is monoecious, with perfect flowers that are pollinated by insects.
- Flowers appear at the ends of new twigs after first leaves are fully developed (early June); flowers may be damaged by late spring frosts.
- Fruit is a drupe, ripening in late August, with bulk of crop falling near parent tree before late autumn.

- Songbirds may distribute seed by regurgitation or by droppings.
- Good seed crops occur every three to four years; individuals produce some seed most years.
- Viable seed is produced in open-grown trees as young as 10 years and in trees as old as 180 years; seed crops decline after 125 years.
- Flower crops are not well related to seed crops.
- Seed production is inversely related to stand density.
- Individual trees tend to be consistent in seed production (i.e., always good or always bad).
- Sprouts readily from stumps of all sizes; those from merchantable-sized stumps generally develop poor form and rot.

2.3.7.3 Establishment

- Seed dormancy requires cool stratification for 120 days.
- Seeds may remain viable for three years or more in soil.
- Seedbed requirements are not rigid; undisturbed leaf litter or exposed mineral soil is satisfactory; compacted soil is a poor substrate.
- Seed buried to a depth of 15 cm in soil may germinate and survive.
- Species is intolerant of shade; seedlings will not survive or grow substantially under closed canopy; requires free or dominant crown to survive.
- May grow 5 to 10 cm within first 30 days of germination; in open conditions, height growth of 45 cm is possible.
- Seedlings develop a tap root when young, which is not seen in saplings.

2.3.7.4 Development

- Height growth is determinate and is 90 per cent complete within eight weeks.
- Species has a medium growth rate (greater than beech and less than red oak).

- Diameter growth is rapid up to age 50 years in pure stands, and may average 10 cm per decade from 10 to 30 years of age.

- In occasional pure, even-aged stands, young trees readily express dominance and differentiate into various crown and diameter classes.

- Generally shows poor response to release; subdominants lack capacity to recover from partial suppression; vigourous trees may show some response to thinning.

- Root system is shallow; trees are subject to windthrow, especially on poorly drained sites.

- Sudden exposure may produce sunscald, stag-head, and general decadence; species is prone to produce epicormic branches.

- Will develop satisfactorily in even-aged patches or strips equal in width to the height of border trees.

2.3.7.5 Damaging Agents

- Annual volume losses due to decay average 4000 m^3 per year from 1977 to 1981 (see Table 3).

- Common causes of brown cubical rot are *Polyporus sulphureus*, *Fomes pinicola* (Schwartz) Cke. (trunk rot), and *Coniophora cerebella* Pers. (butt rot). *Polyporus berkeleyi* Fr. is a common white butt rot.

- Branch mortality and crown-thinning are caused by black knot and cytospora canker. *Nectria galligena* is associated with target canker of stems.

- Defoliation by eastern tent caterpillar and ugly nest caterpillar periodically causes loss of vigour and reduced growth.

- Gum spot, a serious lumber defect, is associated with attacks by the peach bark beetle. Pith fleck is caused by the cambial mining of Dipterous larvae of *Agromyza pruni* and *Phytobia pruinosa*.

- Stems are attacked by peach tree borer, which forms galleries and may provide infection courts for fungi.

- Susceptible to glaze damage and vulnerable to fire.

2.4 Quality Development in Trees

The comparatively high values (noted in Section 2.1.2, "Commercial Importance") that are characteristic of products derived from the major species components of the THWG (at least of the hardwood species) are realized only when the material is of high quality. Any silvicultural undertaking, therefore, must not only recognize quality in the standing forest tree, but also understand how these characteristics can be maintained or improved over time. The recognition and evaluation of both current and potential tree vigour, risk, and quality are crucial elements in successfully applying both uneven-aged systems (which involve marking for individual tree selection), and even-aged systems (which require crop-tree identification and release). In addition, the maintenance of stand productivity objectives for yield and growth rate must be rationalized with these quality requirements and other factors such as site quality to provide maximum volume and value output per hectare.

For more detailed information about appraising individual tree vigour, risk, and quality, refer to *A Tree-Marking Guide for the Tolerant Hardwoods Working Group in Ontario* (Anderson and Rice, in press).

2.4.1 Assessing Individual Tree Vigour Potential

Vigour potential may be defined as the relative capacity of a tree to increase in size (mainly diameter and volume). Management of the THWG is based on the premise that trees to be retained as growing stock will have value-growth potential, which implies a vigour status allowing residual trees to develop quality-specific dimensions in a reasonable period of time.

Numerous vigour indices have been developed for many THWG species for various purposes. Of particular interest are those developed for tolerant hardwoods (OMNR 1983; Mize and Lea 1977; Smalley 1975; Holcomb and Bickford 1952; Gevorkiantz 1956), for mixed hardwoods (DeBald and Mendel 1976; Minckler and Gingrich 1970; Trimble 1969), and for oaks (Trimble 1960; Weitzman and Trimble 1957; Burkle and Guttenberg 1952).

Common to most of these vigour classifications are the following features that should be considered in choosing residual stems (Hamilton 1969; Smith 1954a):

- Crown position:
  Classifying trees by position of their crowns in relation to the forest canopy (i.e., dominant, codominant, intermediate, and overtopped or suppressed) provides an indication of the amount of direct sunlight received, which in turn regulates the photosynthetic rate.

- Crown size:
  The size of the crown (length, width, and volume) is an index of the leaf surface area available to trap light energy for photosynthesis and thus is an indicator of the amount of carbohydrate

manufactured which in turn regulates growth. Crown dimension and space requirements for adequate growth vary with species and are outlined by Arbogast (1957), Smalley (1975), and Marquis et al. (1984) for crown diameter, and by Lorimer (1983), OMNR (1983), Gevorkiantz (1956), and Ward (1964) for live crown ratio (LCR).

- Crown quality:
  Regardless of size and position, the crown must be healthy to perform its function well. Chlorotic or undersized leaves, dead twigs, coarse branches (relative to the species), low leaf density, and flat-topped shape indicate low vigour (OMNR 1983).

- Bark character:
  For some species (notably hard maple, yellow birch, and red oak), tree vigour can be determined by examining the firmness of the bark and the nature of its fissures and ridges. Examples of this technique are outlined in OMNR (1983), Arbogast (1957), Burkle and Guttenberg (1952), Sajdak (1967), and Clausen and Godman (1969).

- Degree of competition:
  The stocking density of nearby, competing neighbours affects the current growth rate of potential crop trees. Removal of competition provides opportunities for growth acceleration and improvement of quality, depending on the state of the factors just discussed and the silvical characteristics of the species.

- Stand relationships:
  Considerations of individual tree vigour must be kept within the perspective of the overall management objectives for stand density, structure, and species composition, as outlined in Section 2.5, "Stand Stocking and Structure."

2.4.2 Assessing Individual Tree Risk Potential

To have value potential, residual trees must survive and grow at least until the next cutting cycle (5 to 20 years). High risk trees are those that may either die or deteriorate significantly in quality due to rot development, etc., during the period. Such trees are usually removed from the forest in early harvesting operations or improvement cuttings. However, in high-graded or abused stands, the average quality is such that some modest-quality trees may have to be retained for stand stocking maintenance. Even high-value, vigorous trees may be of high risk, and therefore of low potential, because of crown damage or excessive lean.

Risk features are accounted for in the hardwood tree classification (see Section 2.4.3, "Assessing Individual Tree Quality Potential") as "decline-causing defects." It is important, however, to discriminate between random decline events affecting occasional trees and multi-species, broad-scale declines of undetermined origin, as noted in Section 3.5.2.2, "Hardwood Decline."

2.4.3 Assessing Individual Tree Quality Potential

There is a fundamentally different philosophy involved in grading hardwood and softwood trees and their products. For hardwoods, species and grade are more important for determining the value of lumber than its volume. Quality hardwood lumber is used for furniture and cabinetry and is graded for appearance, while softwoods, often used for construction, are usually graded for strength (Kasile 1982). The basis of hardwood lumber grading is the number of clear cuttings that can be taken from a board; for softwoods, it is the number and type of defects within a board, and how they affect strength.

From a general point of view, hardwood product quality varies with the following factors in Ontario:

- Tree DBH:
  Value per tree increases with increasing DBH because of a correspondingly larger "quality-zone" component in the logs, which yields a greater percentage of high-value lumber grades such as "selects and better" (Ostrander 1965; Petro 1962).

- Site region:
  In one study, the percentage of "selects and better" lumber grades sawn from grade 1 logs was found to be 30.4 per cent in Site Region 5E compared to 49.3 per cent in Site Region 6E (Morawski 1971).

- Cull factor:
  The overall extent of defect varies with site region, landtype, and species. In Site Region 5E, cull percentage is lower in Algonquin (5E south) than in Algoma (5E north) for hard maple (30 per cent vs 36 per cent),and yellow birch (34 per cent vs 42 per cent) for trees of 46 cm DBH. There is about five per cent less cull in hard maple growing on the Limerick landtype than on the Sherbourne landtype in Site Region 5E (Morawski et al. 1958), perhaps a reflection of the higher soil base content of the former.

- Tree growth rate:
  Potential quality is limited by the type of defect that occurs in a tree. The future growth rate, however, will greatly influence the rate of value development, since the quality of defective trees may improve if their growth rate is sufficiently accelerated.

Estimates of cull (or quality) in hardwoods can be further refined by using tree classifications that recognize defect indicators and log quality and volume in the standing tree. A conceptual outline of a system used in the Algonquin Region is shown in Table 4.

Descriptions of the features used in this classification have been published by numerous authors: Shigo (1984a, 1984b, 1983, 1965); OMNR (1983, 1973); Rast (1982); Basham and Anderson (1977); Carvell et al. (1973); Stayton et al. (1971, 1970); Marden and Stayton (1970); Stayton

TABLE 4: Algonquin Region Tolerant Hardwood Tree Classification (Conceptual)	
Tree Class	**Class Description**
A1	Trees that contain or are potentially capable of producing high-quality logs and that are expected to at least maintain their present quality for a 20-year period. Such trees would normally be considered crop-tree producers of high-quality sawlogs or veneer logs.
A	Trees that have bole quality equal to Class A1 trees, but that are of high risk or are expected to decline within a 20-year period. Such trees are normally best harvested immediately.
B1	Trees that contain or are potentially capable of producing medium-quality logs and that are expected to at least maintain their present quality for a 20-year period. Such trees would normally be considered crop-tree producers of sawlogs for dimension lumber.
B	Trees that have bole quality equal to Class B1 trees, but that are of high risk or are expected to decline within a 20-year period. Such trees are normally best harvested immediately.
C	Trees containing or having the potential to produce low-quality logs but no better. Such trees are often used for pulpwood, poker poles, bolter logs, or fuelwood but are not normally considered as crop trees.
D	Cull trees by Crown Timber Act standards: no sawlog potential, but that may be used for pulpwood or fuelwood if a strong market exists. **Note:** Merchantable hardwood trees contain one or more merchantable logs to a 22 cm top having a total content of sound wood that is equal to more than 50 per cent of the content of all the logs in the trees.
Defects	
Value-affecting defects are mechanical or form defects. These defects limit or reduce the value of products that can be recovered from a tree but will not cause continued deterioration or decline. The size and position of these defects determines the degree to which they affect value. (Examples: wounds, cracks, seams, holes, dead limbs, branch stubs, live branches, twisted grain, bumpy surface, sweep, crook, forks, burls, and lean.) **Decline-causing defects** are severe mechanical or pathological defects. These defects cause continued deterioration of the products that may be recovered from a tree. They may also severely limit the potential of a tree to produce anything better than low-value products (e.g., pulpwood, poker poles, bolter logs, and fuelwood). (Examples: rot or decay when associated with value-affecting defects or when indicated by the presence of conks, fruiting bodies, cankers, barrelling, etc. Severe mechanical defects such as broken top, excessive lean, or severe sugar maple borer damage will cause decline or cause the tree to be of high risk.	

and Marden (1970); Shigo and Larson (1969); Lavallee (1968); Lavallee and Lortie (1968); Lockard et al. (1963); Hesterberg (1957b); Silverborg (1954); Zillgitt and Gevorkiantz (1948); and Hepting et al. (1940). Guidelines for quality-product grade specifications for hardwood growing stock have been presented by Boyce and Carpenter (1968), Sonderman (1979) and Sonderman and Brisbin (1978). Additional information on fungal, insect, and abiotic effects is outlined in Section 2.3, "Silvics."

Harvesting, and the estimation of volume and value involved, is an important element of silviculture. However, a silvicultural tree classification system must not only assess current quality in terms of product and value, but also evaluate the potential of a tree to respond to treatment, and to increase, decrease, or maintain its quality over the management period. Such information is essential to determining the appropriate silvicultural system (using quality cruise data), formulating marking prescriptions, estimating harvest volume and value, and estimating residual standing crop and its potential growth and yield. It also facilitates the marking process by discriminating among similar crowded trees (i.e., indicating the trees of greatest potential).

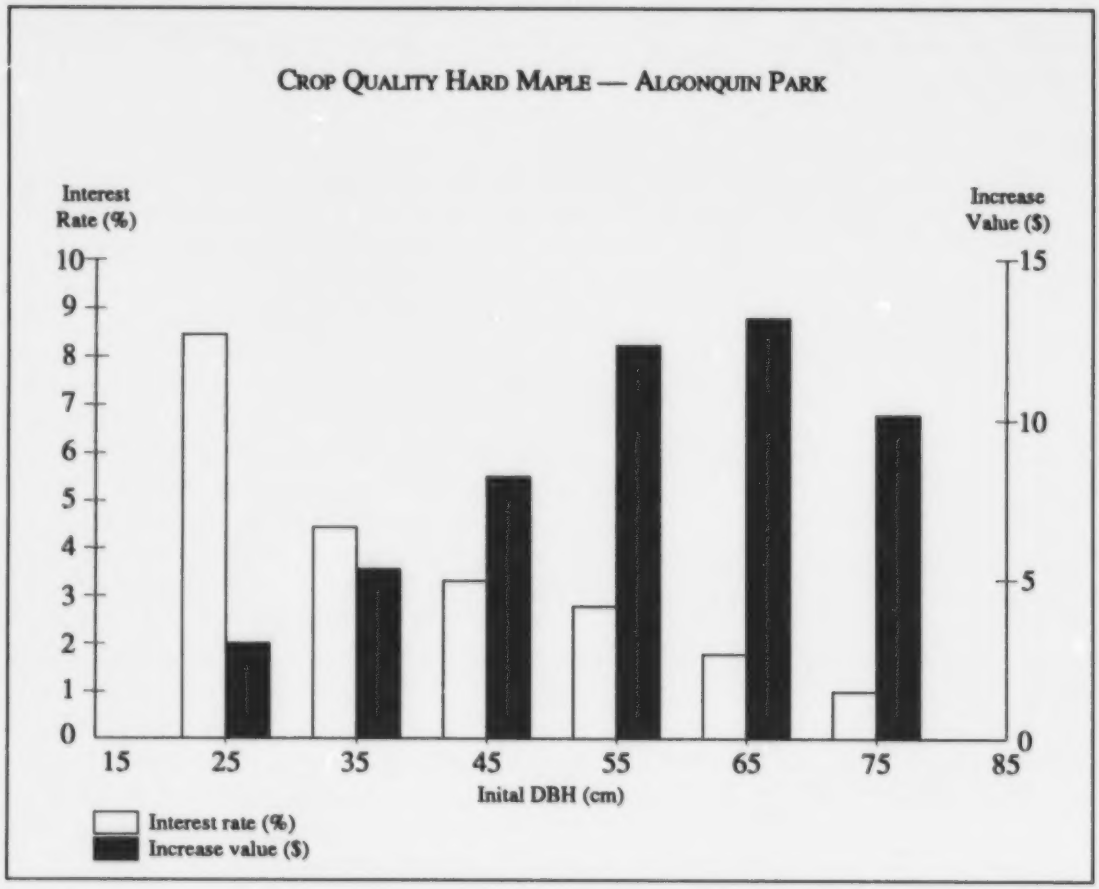
In the Algonquin classification (see Table 4), trees are graded for potential value based on current quality or risk of decline (i.e., trees are classified as "A" for present high quality but low potential, and "A1" for high potential quality). Other classifications may simply classify the trees as "acceptable growing stock" (AGS) or "unacceptable growing stock" (UGS). The Algonquin system can be simplified during compilation (A1 and B1, for example, are AGS), if desired.

Lumber recovery studies carried out in Algonquin Park (McLean 1970; Anderson and McLean 1970) suggest that, if conversion costs are ignored and tree grade, merchantable length, and lumber prices are assumed to be constant over time, nominal interest earned by trees growing at a rate of five centimetres in DBH over ten years decreases with increasing initial diameter. While there is a large differential in the increase in recoverable value of 66 cm trees ($13 in 1968) compared to 25 cm trees ($3 in 1968), the interest rate earned by high quality trees of these sizes is inversely related to tree size and varies with potential growth rate (see Figure 6).

From a silvicultural perspective, therefore, medium-sized sawlog trees of good vigour and quality earn value at a higher rate and occupy less space in the stand than larger trees, and are a better economic investment. Strategically, the manager attempts to transfer the growing space occupied by larger, mature trees to the high-potential, smaller, sawlog-size trees, by means of marking and harvesting. DeBald and Mendel (1976) have suggested methods to develop financially sound silvicultural approaches to hardwood management.

In even-aged stands, the relevant question for management involves the length of the rotation. In uneven-aged selection forests, the important question is related to how long an individual tree should be allowed to grow. Once an ideal stand structure is approached in a selection forest, the concept of financial maturity can become a factor in tree marking. One aspect of this process is to determine maximum diameters appropriate for individual trees of various qualities, merchantable lengths, and potential growth rates (see Table 5). These mature diameters can be selected on the basis of economic rate of return (allowing for conversion costs).

FIGURE 6: Relationship between interest rate earned and lumber value increase (1968 $) for crop-quality hard maple growing five centimetres in DBH in ten years (from Anderson and McLean [1970])



In consideration of these results, a general guideline for initial conditioning cuttings in the THWG would be to use a maximum diameter of 60 cm in determining maturity. However, other considerations—for example, modifications for wildlife habitat improvement, or aesthetics—might change this structural limit. In some cases, trees larger than the economic optimum may be justifiably retained for some species. Conversely, in the northern transitional forest, growth rates and quality may be such that a maximum DBH less than those suggested by Table 5 may be justified.

2.5 Stand Stocking and Structure

Optimization of growth and development in the THWG occurs only when the stands are regulated in terms of stocking density and its relationship to size-class distribution and cutting cycle for uneven-aged stands and to age for even-aged stands. Consideration of species, site

TABLE 5: Financially Mature Diameters for Hardwood Species of Butt-Log Grade 1 and 2, Based on Growth Rate Alone Over Ten Years (from Mendel et al. [1973], Grisez and Mendel [1972], Mendel and Trimble [1969], and Trimble and Mendel [1969])

Species	Vigour Class	Rate of Return		
		2%	4%	6%
		Mature dbh cm (in)		
Mh	1	69 (27)	51 (20)	43 (17)
	2	61 (24)	46 (18)	38 (15)
	3	56 (22)	41 (16)	36 (14)
Aw	1	76+ (30+)	56 (22)	41 (16)
	2	69 (27)	46 (18)	36 (14)
	3	58 (23)	36 (14)	-
Cb	1	76+ (30+)	56 (22)	41 (16)
	2	76 (30)	43 (17)	33 (13)
	3	69 (27)	-	-
Be	1	58 (23)	48 (19)	43 (17)
	2	51 (20)	43 (17)	41 (16)
	3	48 (19)	41 (16)	-
Or	1(SI 24[80])	71 (28)	56 (22)	51 (20)
	1(SI 18[60])	61 (24)	51 (20)	46 (18)
	2(SI 24[80])	64 (25)	53 (21)	46 (18)
	2(SI 18[60])	58 (23)	48 (19)	41 (16)

management objectives, products desired, and economic constraints also modifies management procedures on a local scale. This section will outline, for (i) uneven-aged, and (ii) even-aged systems, the basic models that should be used as reference points in setting stand management goals. A comparison of stand attributes of even- and uneven-aged systems is given in Table 6. A more comprehensive discussion of this topic is contained in *A Tree-Marking Guide for the Tolerant Hardwoods Working Group in Ontario* (Anderson and Rice, in press).

2.5.1 Stand Stocking

By definition, stand *density* is expressed numerically on a per-unit-area basis, while *stocking* is a relative term, considered in relation to the stand desired for best growth (Bickford et al. 1957). In this discussion, the term *stocking level* is used synonymously with *density level*, to reflect the common local usage of the term in uneven-aged silviculture. These terms are used in their more traditional sense, however, in discussing even-aged management.

TABLE 6: Stand Factors Affecting Determination of Growth and Yield in Hardwoods (from Schlaegel [1978])

EVEN-AGED	UNEVEN-AGED
AGE STRUCTURE	
◆ All trees essentially of same age ◆ Stand age indicates physiological maturity ◆ Age used to determine parameters such as diameter, height, basal area, volume, and site index	◆ Continuous age distribution ◆ Stand age does not exist ◆ Conventional yield tables and growth equations do not work ◆ Number of years since treatment is useful for prediction
DIAMETER DISTRIBUTION	
◆ Normal or skewed-normal distribution ◆ Most trees grouped about the mean ◆ Can use average diameter, range, and standard deviation for comparisons ◆ Can use normal probability density function to predict diameter distribution	◆ Reverse-J-shaped distribution ◆ Average stand diameter cannot be interpreted ◆ Can use exponential or Weibull probability density function ◆ Growth rates predicted by stand table projection by diameter class from permanent sample plots
BASAL AREA	
◆ Basal area increases to an asymptote ◆ Growth pattern is sigmoid, starting slowly, accelerating, then slowing to a constant	◆ Basal area nearly constant except for minor fluctuations due to mortality or selective harvesting followed by ingrowth
HEIGHT	
◆ Average height development is sigmoid, increasing to an asymptote ◆ Site index is calculated from dominant trees ◆ Suppressed trees contribute little	◆ Average height of tallest trees tend to be constant over time ◆ Growth potential of individual trees related to crown vigour and position in canopy ◆ Suppressed trees may be future growing stock

Stocking levels in the THWG are normally expressed in terms of basal area per unit land area (Zillgitt 1949), because such values are readily obtainable from point sample estimates and they form part of the silvicultural stand development model. Stocking is less commonly expressed in terms of volume per unit area and can be estimated from basal area or developed by applying appropriate regional cull figures to gross merchantable volume (GMV) estimated from cruise data (species, DBH, merchantable length, tree quality) and standard volume tables (e.g., Form Class 79). For unmanaged even-aged stands, general estimates can be derived from site class yield tables (Plonski 1981; Love et al. 1972).

2.5.1.1 Uneven-aged System

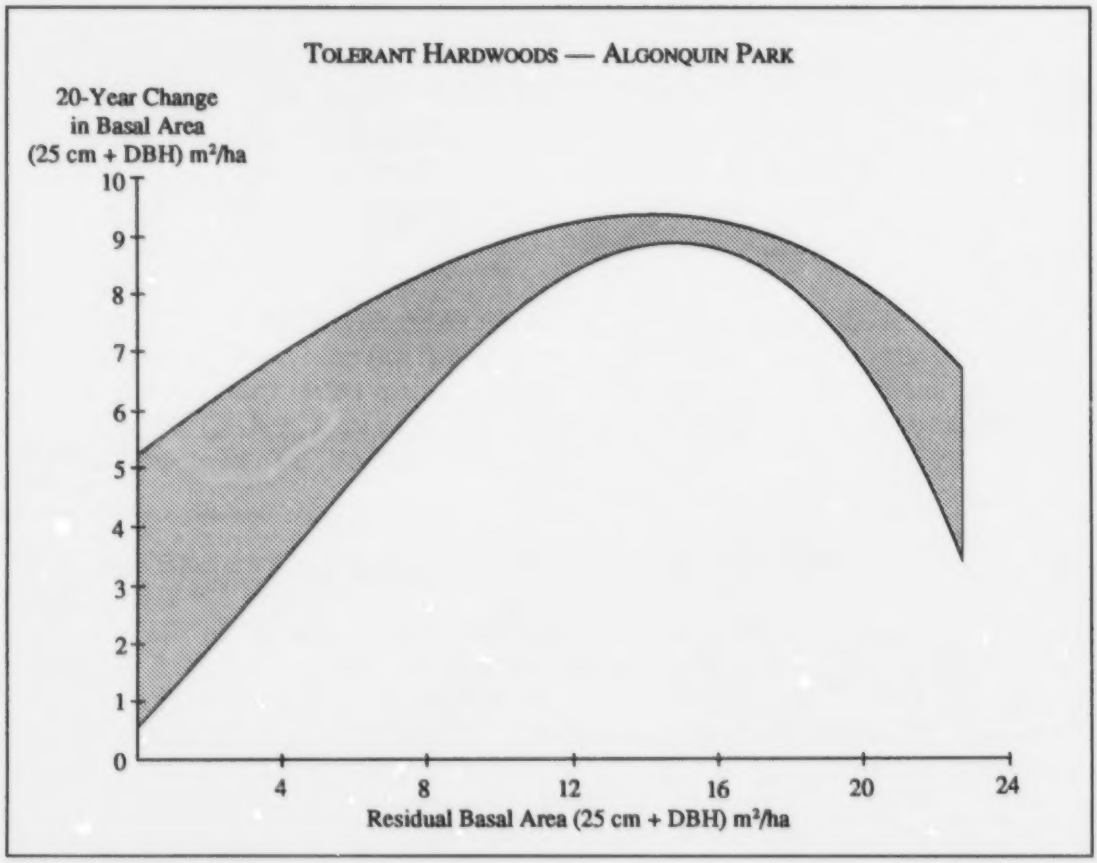
It is convenient (and conventional) to consider basal area stocking in terms of stand components. These are (i) total basal area in trees greater than 1 cm DBH, (ii) basal area in trees greater than 9 cm DBH, and (iii) basal area in trees greater than 24 cm DBH. These are respectively considered to represent (i) recruitment, (ii) polewood growing stock, and (iii) sawlog components. In special cases, basal area in trees greater than 50 cm DBH may be used to represent "maturing" trees.

Depending on species mixture, local site quality, and site region, mature hardwood stands frequently have stocking levels averaging about 35 m^2/ha of total basal area. The distribution of this basal area may vary widely among stand components depending on site and, more importantly, stand history. Undisturbed stands usually have much of their basal area in the largest-sized trees and have developed a two-storied appearance. High-graded or unmanaged stands may have little basal area in large trees, except for cull, because of intense, uncontrolled harvesting of merchantable-sized trees in the past. McLean (OMNR 1983) analyzed the 20-year basal area growth of uneven-aged stands in Site Region 5E and found production maximized at a residual basal area of about 14 m^2/ha in trees greater than 24 cm DBH (see Figure 7). At basal areas higher than this, the stand is overstocked, usually with larger, mature trees suppressing the smaller sizes. At lower levels, no suppression occurs, but the growing space is under-utilized.

For more southerly portions of the THWG range, such as Site Regions 6E and 7E, the results of the pioneering work of Crow et al. (1981), Arbogast (1957), and Eyre and Zillgitt (1953) in the Lake States may be more appropriate. Such studies suggest retaining residual basal areas of 16 m^2/ha in trees greater than 24 cm DBH for producing high-value products.

The choice of residual stocking level cannot be set independently but must be considered with reference to the length of the cutting cycle. The manager might vary the cutting cycle according to the residual stocking level required and the minimum volume to be grown for the next cut. Under all options, longer cycles require lower initial basal area levels (see Table 7). Under economic constraints, for example, the higher costs of roads necessary to access stands may require heavier cutting to justify such costs, resulting in associated lower residual densities, and thus longer cutting cycles. In the Algonquin Region, initial implementation of uneven-aged management was based on a 20-year cycle. The faster growth rates and better timber quality of stands in Site Regions 6E and 7E are well-suited to a 15-year cycle initially. Once stands become

FIGURE 7: Basal area growth of tolerant hardwoods in Algonquin Park related to residual stocking (OMNR [1983])



regulated, it may be possible—in fact, preferable—to reduce the length of the cutting cycle. Evidence from good sites in Site Region 5E indicates that cycle lengths of 12 years are feasible. Table 7 indicates estimated cutting cycle lengths for various management objectives in regulated stands.

In some cases, poor trees may be left within the stocking target for site protection and to provide stocking to improve bole-form of residual crop trees. In badly degraded or abused stands on adequate sites, stocking levels may be chosen below optimum to accelerate recruitment of better-quality trees. In the Algonquin Region, residual stocking levels should not be set lower than 11.5 m^2/ha in trees greater than 9 cm DBH, and at least 75 per cent of this must be in crop-quality trees (acceptable growing stock). Full stocking should be obtained within no more than two cutting cycles.

2.5.1.2 Even-aged System

In uneven-aged stands, trees of all ages are spatially intermixed within the stand, which is grown

TABLE 7: Length of Cutting Cycle Required to Grow Target Volumes in Algonquin Region from Various Residual Stocking Levels (Adapted from OMNR [1973])

Residual Basal Area Crop Trees > 25cm DBH (m^2/ha)	Minimum Volume Required for Next Cut (m^3/ha)						
	10	20	30	40	50	60	70
	Cutting Cycle Length (years)						
3	16	23	30	37	44	51	58
6	8	13	18	23	28	34	39
9	5	10	14	19	23	28	32
12	4	8	12	16	21	25	29
15	3	7	11	15	19	23	27
18	3	6	10	14	18	22	26

continuously without uniform rotation length. In even-aged stands, a discrete population of trees of similar age are grown as an entity from establishment to harvest on a specified rotation cycle. A forest comprising a regulated series of such stands is managed in terms of the *areas* occupied by specific age classes (stands) whereas uneven-aged forests are managed by *volume* in terms of specific numbers of trees in each DBH class.

The curve of growth over time in an even-aged forest is sigmoid in shape, increasing to a maximum, then declining. An unharvested stand, if left long enough, will have net growth that will eventually become negative when mortality exceeds accretion. The culmination of the mean annual increment (MAI) is often used to determine rotation age in cases where maximum timber production rate is the prime objective of management. Use of any rotation age other than that shown by the culmination of MAI will result in a lower average rate of production (Clutter et al. 1983).

Other objectives, however, may dictate choice of rotation length—for example, specification of product sizes required; maximization of annual net value growth; or maximization of return for specified discount rates. Rotations may be as short as 50 years for fibre products, and as long as 200 years where aesthetics are the prime concern (e.g., with hemlock). With hard maple and yellow birch, rotations are frequently placed at 90 to 120 years, depending on site and intensity of management (Tubbs 1977b).

Rotation lengths can be substantially decreased by appropriate tending and thinning treatments. Marquis et al. (1984) recommend a medial DBH of 45 cm for merchantable-sized trees as the point where stands should be harvested. This could be achieved in 87 years for veneer-grade

yellow birch if crop-tree release is commenced early (Erdmann 1987). Normally, cultural entry is made into even-aged stands at frequent intervals to control species composition, eliminate poor quality, and accelerate the growth of crop trees. For best growth and quality development, increasing amounts of basal area and decreasing numbers of trees are retained as average stand diameter increases (Erdmann 1987).

The most commonly used method of density control for even-aged stands was developed by Gingrich (1964, 1967) for upland central hardwoods in the United States. An overview of this stocking guide concept and its use can be found in Ernst and Knapp (1985). Metric versions for some types of stands have been developed (Rogers 1980).

Closed-canopy stands containing trees with minimum crown area represent the "maximum" level of stocking. A second condition of closed-canopy, where each tree has maximum required growing space but no more (crowns fully developed and just touching), would represent the "minimum" level of stocking for full site utilization.

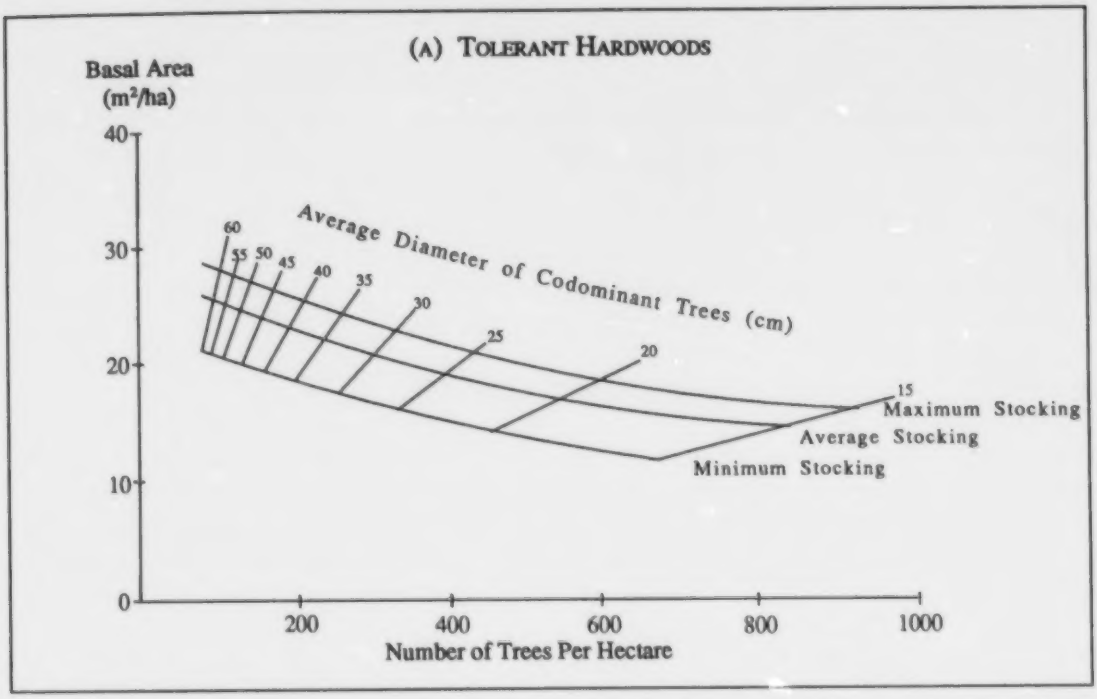
These stocking guides (of the type developed by Gingrich) indicate, for a given number of trees and basal area per acre, the per cent stocking and quadratic mean diameter ($\overline{D}q$) for the stand. The guide shows how completely a particular stand is occupying its area, and also how much of a stand may be removed without wasting growing space. Stocking per cent can be calculated as the ratio of actual basal area to guide basal area for a given $\overline{D}q$. The fastest diameter growth will occur near the minimum density required for full site utilization—about 58 per cent of full stocking.

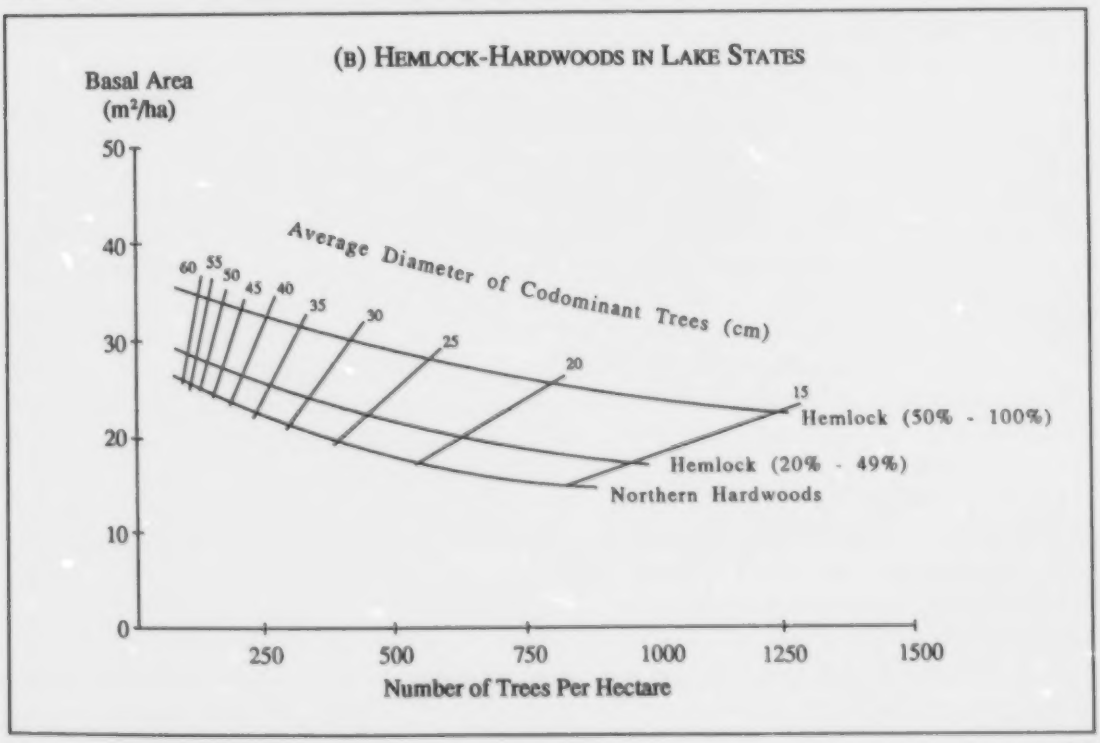
The stocking guides given in Gingrich were developed from stands dominated by oak in unglaciated areas of the central United States and are recommended for intolerant hardwoods (Gingrich 1971; Roach and Gingrich 1968). Similar methods have been used to develop guides for northern hardwoods in New England (Leak et al. 1969) and the Lake States (Tubbs 1977b), for mixed stands in the Allegheny area of the United States (Roach 1977), and for red oak in New England (Sampson 1983).

The guides for the Lake States (see Figure 8) would be most appropriate for application to Ontario conditions. Using such charts, Tubbs (1977b) recommends for stands of hard maple, yellow birch, and white ash (Figure 8a) that the residual stocking level not be reduced below 80 per cent of "average stocking." Stocking levels should not be allowed to decrease below 14 m^2/ha if bole quality is to be maintained by natural pruning (Erdmann 1987). For northern hardwoods containing more than 20 per cent hemlock (Figure 8b), the stands should be marked in proportion to the amount of hemlock to be left. Residual stocking may be maintained at a high level with short cutting cycles to discourage hardwood establishment or to enhance aesthetics.

In northern hardwood stands of mixed species composition, stocking guides should account for the different growing-space requirements of each species. The concept of *relative density*, which assigns different space requirements to three groups of species based on shade tolerance, may be effectively used. Relative density is computed as a composite of each species' contribution to the mixture (Stout 1987).

FIGURE 8: Stocking levels for even-aged stands of (a) tolerant hardwoods with less than 20 per cent conifer, and (b) hemlock-hardwoods in Lake States by basal area and numbers of trees for specified diameter classes (modified from Tubbs [1977b])





2.5.2 Stand Structure

The manner in which individual trees from seedling to sawtimber sizes are arranged in a stand is termed *structure*. Stand structure represents the distribution of size or age classes in a crop. Typically the relationship of number of trees by diameter class forms a "reverse-J-shaped" curve in uneven-aged stands, and a "bell-shaped" curve in even-aged stands. An ideal structure allows full utilization of growing space and thus maximizes the growth rate that is possible at ideal stocking levels.

2.5.2.1 Uneven-aged System

A stand on a good site stocked with high-vigour, low-risk trees and having a range of diameters that fully uses the growing space would tend to grow at the maximum rate. A balanced structure, with all required size classes present, ensures that there is always a supply of growing trees developing into harvestable products.

McLean (OMNR 1983) recommended the size-class distribution shown in Table 8 for tolerant hardwoods managed for high-quality products in uneven-aged systems on a 20-year cycle in Algonquin Park (Site Region 5E). For preliminary practical use, the data can be compressed so that approximately 15 to 35 per cent of basal area is partitioned among each of four composite DBH classes.

In most stands to be put under uneven-aged management, one or more cutting cycles will be necessary before the recommended stocking of high-quality trees can be achieved. The difference between the stocking requirement and crop-tree stocking must be made up initially by leaving trees of poorer quality. It is also important to realize that this "ideal" condition can never be reached in all parts of the stand at one time, but is the average at which to aim. Through management efforts (i.e., marking), the stand, over time, should contain a progressively greater proportion of acceptable growing stock (classes A1 and B1).

A diagram of the data in Table 8 showing the frequency distribution of diameter classes indicates a "reverse-J-shaped" curve (see Figure 9) whose characteristics are determined by several factors:

- Maximum diameter to be retained:
  A function of economic maturity as outlined in Section 2.4, "Quality Development in Trees," and of other factors such as aesthetics. In Site Region 5E, 60 cm is commonly used.

- Stocking level or stand basal area:
  Dependent on site potential; commonly set at 14 m^2/ha in trees 25 cm DBH and greater in Site Region 5E.

- Length of cutting cycle:
  Reflects site potential and the economics of access and yield expectation; commonly set at 20 years in Site Region 5E.

TABLE 8: Recommended Residual Stand Structure for Uneven-Aged Tolerant Hardwoods Managed for High-Value Products by the Selection System on a 20-Year Cycle (from OMNR [1983])

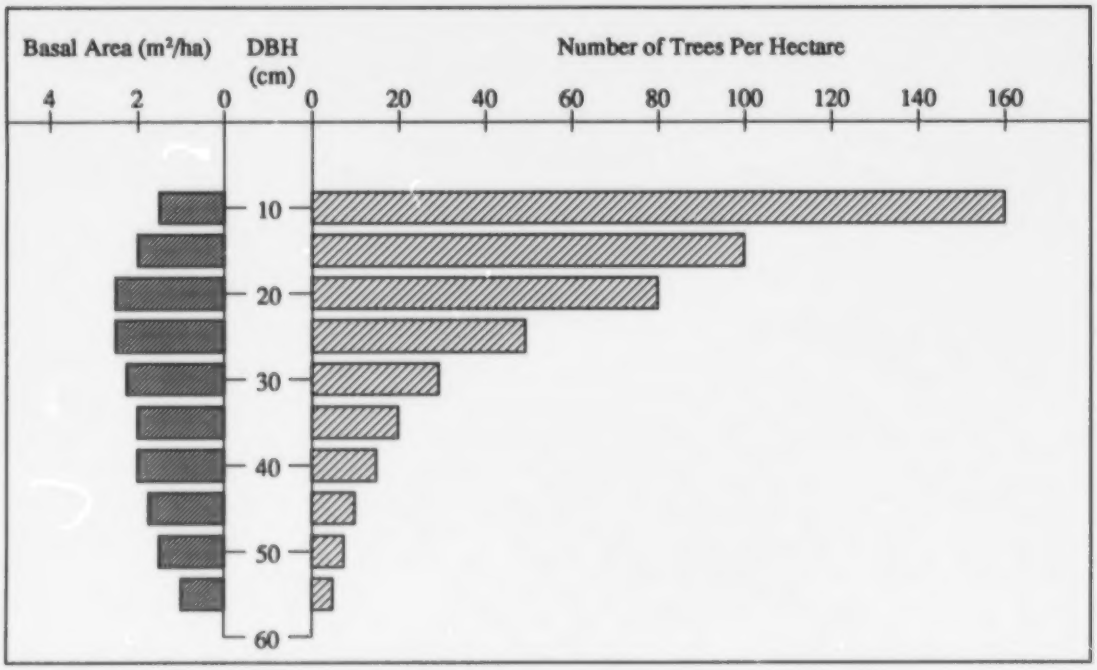
DBH Class		Number of Trees		Composite Number		Basal Area		Composite Basal Area	
CM	IN	HA	AC	HA	AC	M^2/HA	SQ FT/AC	M^2/HA	SQ FT/AC
11.4	4.5	161	65			1.6	7		
16.5	6.5	101	41	334	135	2.1	9	6.2	27
21.6	8.5	72	29			2.5	11		
26.7	10.5	47	19			2.5	11		
31.8	12.5	30	12	96	39	2.3	10	6.9	30
36.8	14.5	20	8			2.1	9		
41.9	16.5	15	6			2.1	9		
				25	10			3.9	17
47.0	18.5	10	4			1.8	8		
52.1	20.5	7	3			1.6	7		
57.2	22.5	5	2	12	5	1.4	6	3.0	13
62.2	24.5	0	0			0	0		

- Minimum diameter considered:
  Reflects merchantability standards; usually set at 9 cm.

The shape of the frequency distribution of diameter classes reflects the regulated nature of the stand structure. Progressively larger numbers of successively smaller-sized trees are retained to provide recruitment capital to fill gaps created by periodic mature and overcrowded tree removals.

A balanced distribution is exponential and the average quotient between numbers of trees in consecutively smaller (five centimetre) DBH classes tends to be constant and was termed a "Q-value" by Meyer (1952). For any distribution, an approximate Q-value can be determined by fitting a straight line to the relationship between the logarithm of frequency of stems to DBH class. Q-value is calculated as the antilog of the product of class interval multiplied by the slope coefficient. The methods described by Tubbs and Oberg (1978), Leak (1963), and Hutnik (1958) may be consulted for additional detail. Smith and Lamson (1982) have published tables of distributions based on varying Q-value, maximum DBH, and residual basal area.

FIGURE 9: Stand and stocking targets recommended for selection management in Algonquin Region

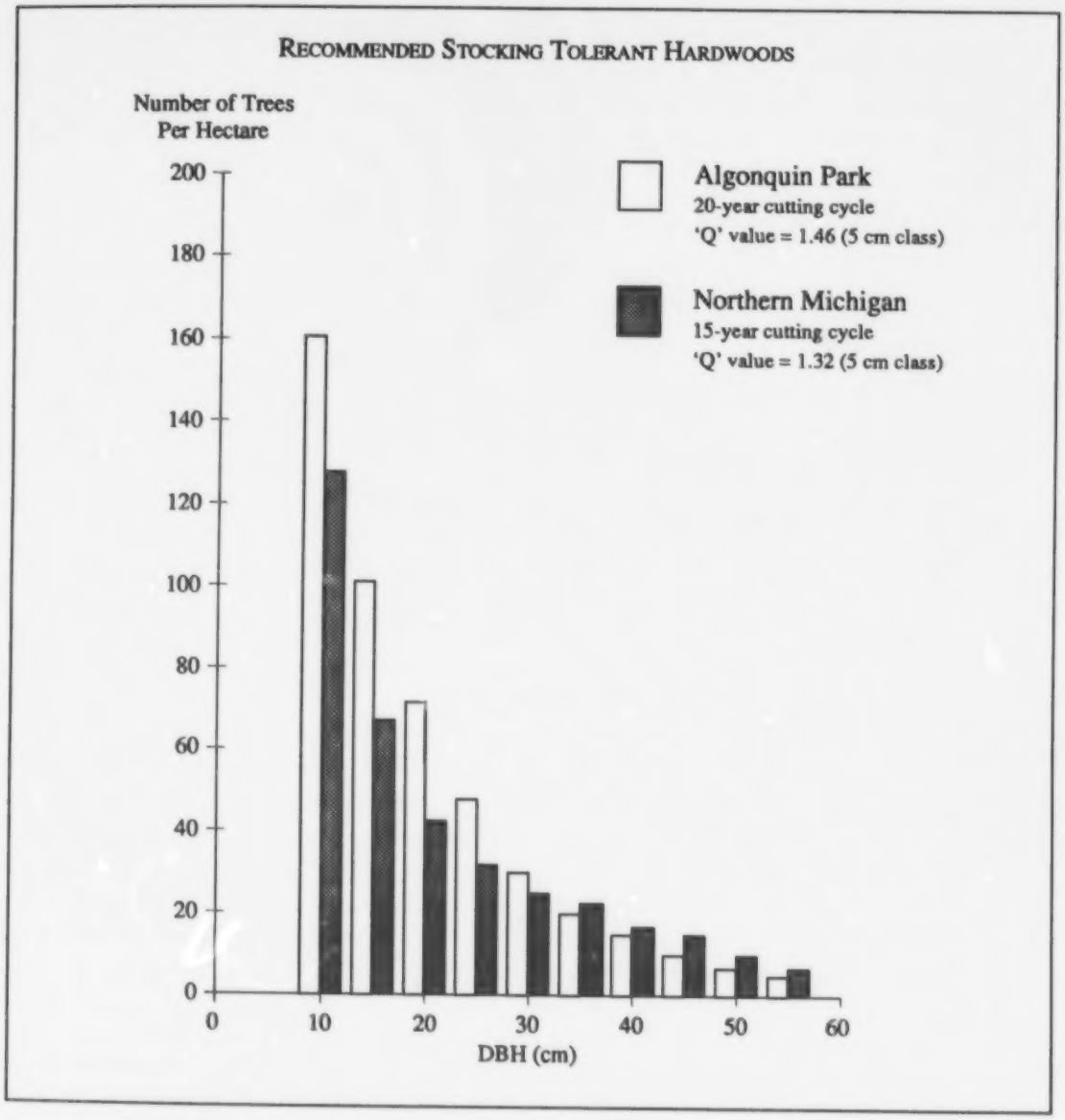


Simulation studies have concluded that these parameters should vary depending on the management objectives (Hansen and Nyland 1987). In some cases, a single Q-value may not be adequate to describe the shape of the most productive stand structure. A dynamic Q-value or a more complex function may be more appropriate. A more comprehensive discussion of these options is outlined in *A Tree-Marking Guide for the Tolerant Hardwoods Working Group in Ontario* (Anderson and Rice, in press).

Stand structure targets should reflect the potential of the site to produce wood. In Site Regions 6E and 7E, the structure recommended for timber production in the Lake States (Arbogast 1957) is more appropriate than that discussed for Site Region 5E. In Figure 10 the recommended size-class distributions are compared for the Algonquin Region and the Lake States region.

The two curves differ: Algonquin Region values are lower in sawlog portions and a little higher in polewood portions. This reflects a longer cutting cycle (20 years vs 15 years) and somewhat poorer site and growth conditions in the Algonquin Region, and agrees with recommendations by Eyre and Zillgitt (1953) to reduce sawlog stocking by 15 per cent if cutting cycles are increased by 5 years. The Algonquin curve also reflects a lower overall target stocking level (14 m^2/ha vs 16 m^2/ha in trees 24 cm DBH and greater), to allow stands to grow an additional five years without becoming overstocked. The difference in relative shape of the curves is also reflected in their different Q-values (Algonquin = 1.46 and Lake States = 1.31 for 5 cm DBH classes).

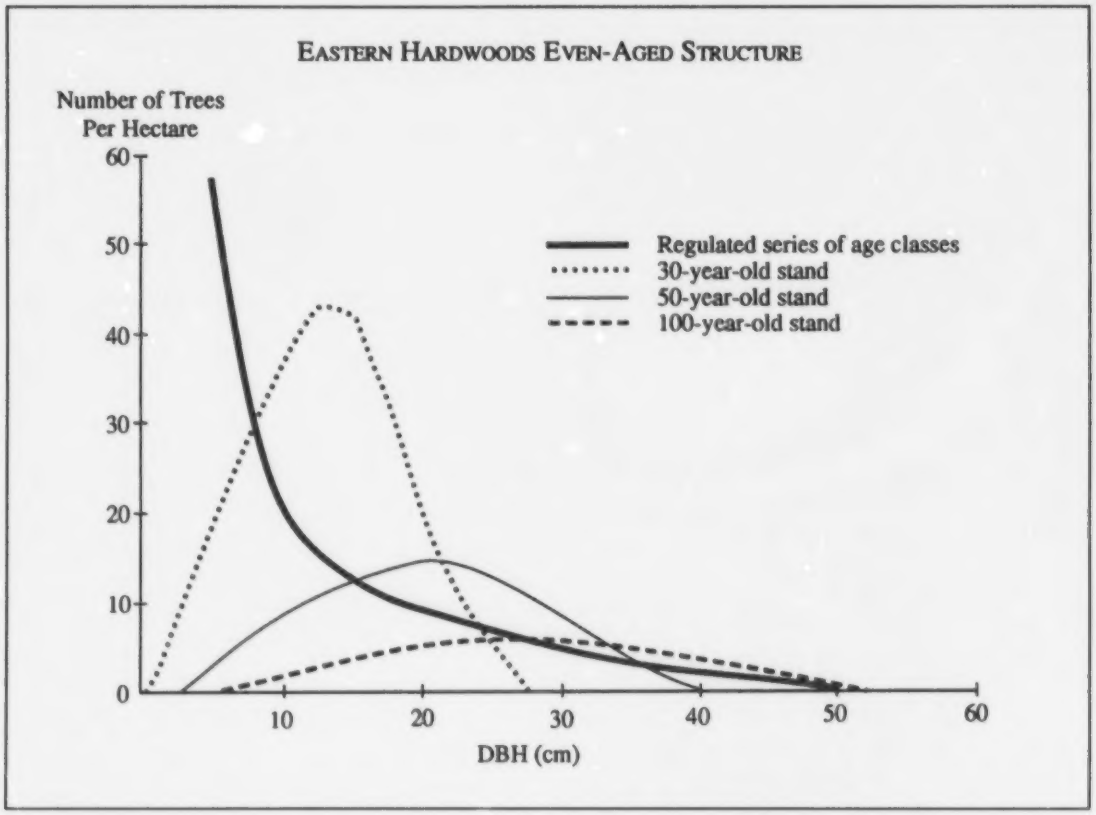
FIGURE 10: Comparison of stand structures recommended for selection management of tolerant hardwoods in Algonquin Region and in the Lake States (OMNR [1983] and Arbogast [1957])



Similarly, Q-values set for THWG stands in the northern transitional forest may need to reflect more limited site potential.

Stands managed under the group-selection system may use the same guidelines as those for single-tree selection, although cultural work in the understory (for regeneration purposes) will not benefit stand production appreciably (Leak and Gottsacker 1985).

FIGURE 11: Stand- and forest-structure developed under regulated even-aged system (from Smith [1960])



2.5.2.2 Even-aged System

Even-aged *stands* tend to be composed of trees of similar size, creating a size-class distribution or structure that tends to plot as a normal or bell-shaped curve (see Figure 11). However, a *forest* composed of many even-aged stands of varying age managed in a regulated series will exhibit an inverse-J-shaped curve rather than a normal one (Smith 1960).

Methods for optimizing residual diameter class distributions for thinning even-aged stands have been developed by Roise (1986), using a non-linear programming algorithm. Similarly, Chen et al. (1980) demonstrated the use of dynamic programming to optimize stand density over time for even aged stands.

Stand structure is greatly influenced by the type of thinning or intermediate cutting employed: crown thinning (from above), low thinning (from below), selection thinning, or mechanical thinning (Erdmann 1987). Studies in which plots were cut to constant relative density, but by different methods to yield a variety of structures, showed that plots cut from above had negative growth for the first five years after thinning, while plots cut from below had many dominant and

codominant stems that grew very well. Trees that were growing best before thinning are the ones to leave as residuals to optimize stand growth (Stout 1987). This means that crop trees generally should be chosen from the upper half of the diameter range (Roach and Gingrich 1968). Cutting primarily from below will open the canopy sufficiently to stimulate a growth response in the residual upper-canopy trees.

Gingrich (1967) studied the structure of upland hardwoods in the central United States and found that young stands exhibited moderately skewed (positive) diameter distributions, which tended to normalize as the stands grew older. He concluded that stand structure could be ignored in the appraisal of stocking and that it had only a minor effect on volume growth.

In a regulated stand, basal area and volume growth on a given area should not vary, with either system, to any extent over a wide range of residual densities. Within this range, stand structure can be manipulated to provide the kind of growth needed by management (Jacobs 1968). For example:

- increase density to improve tree quality;
- decrease density to accelerate diameter growth;
- for tolerant species, transfer growth to the sapling portion of the stand.

2.6 Stand Growth and Yield

The yield of tolerant hardwood forests is influenced by a great variety of factors. It depends on available markets and the degree of utilization practiced during forest harvesting. The sawlog content of trees under current standards constitutes 65 to 75 per cent of stem volume, and tends to increase with tree size. An additional 15 per cent (down to a 10 cm top) can be recovered for pulp or fuel. The remaining 10 to 20 per cent is unused under most circumstances (Love et al. 1972).

For specified products, the size, age, and quality of the trees in the stand exert a great influence on yields. A stand may be very productive in biomass terms, but yield only low volumes of high-quality sawlog material. This is often an effect of site condition but may reflect cutting history, being typical of degraded stands.

Potential yield is determined not only by site quality, but also by species composition and the appropriateness of management prescriptions. The recognition of tree and stand potential for growth and yield, and a discussion of techniques for manipulating forest development, is outlined in Sections 2.4, "Quality Development in Trees"; 2.5, "Stand Stocking and Structure"; and 3.1, "Silvicultural Systems."

The various data reviewed in this section may not be strictly comparable because the terms of reference are not necessarily similar (for example, studies may refer to accretion or production, to total or merchantable volume, and to periodic or mean increment, etc.). An overview of some results published in Ontario is shown in Table 9. Because of the limited nature of these data, Table 10 is included to provide additional information from U.S. studies that may be appropriate for some southerly Ontario sites. Readers interested in using any of these data in a specific manner should consult the original source documents.

2.6.1 Unmanaged Forests

According to Bickerstaff et al. (1981), the overall mean annual increment (MAI) of gross merchantable volume (GMV) on productive forest lands in Ontario is 1.7 m^3/ha/yr. In the Great Lakes-St. Lawrence Forest Region, the range of MAI (1.5-2.5 m^3/ha/yr) among component sections is slightly higher than in the "Boreal Continuous Forest." Four sections (L.1, L.2, L.4c, and L.8, shown in Figure 1) have averages in excess of 2.0. The overall average MAI in the Deciduous Forest Region (D.1) is 2.7 m^3/ha/yr, second only in Canada to Coastal British Columbia.

Normal yield tables, developed by Plonski (1981, 1960) provide guidelines for estimating site class for tolerant hardwoods growing in pure, even-aged stands. These tables were designed to reflect conditions across Ontario and serve the particular requirements of inventory and forest management planning on a broad scale. They are not intended for predicting volume in individual stands. These relationships have been formulated by Payandeh (1973) to facilitate computer analysis. For assumed rotation lengths of 90, 95 and 100 years, respectively, for tolerant hardwood site classes 1, 2, and 3, the associated GMV (and MAI) are estimated to be 209 (2.3), 171 (1.8), and 138 (1.4) m^3/ha, respectively, using an average stocking factor (for hard maple) of 75 per cent.

Love et al. (1972), working in Site Regions 5E, 6E, and 7E, developed normal yield tables for hardwood stands according to four site-quality classes (Ontario Land Inventory) and two groups of species (based on shade tolerance). At the index age of 50 years, in stands composed of more than 80 per cent hard maple and beech, MAI of GMV on the best site is estimated to be 3.64 m^3/ha/yr. Stands composed of less than 50 per cent hard maple and beech show 16 to 20 per cent better production rates due to the faster growth rates of the less-tolerant species.

Working on the Precambrian Shield in Site Region 5E, Raymond and McLean (1984) estimated the periodic annual growth of uneven-aged tolerant hardwood stands after unprescribed partial cuts of various intensities and chronologies to average 0.37 m^2/ha/yr of basal area and 1.52 m^3/ha/yr of net merchantable volume growth. In overmature stands, there is often a condition of "zero net growth" in which new growth is offset by increasing cull and mortality.

2.6.2 Managed Forests

2.6.2.1 Uneven-aged Stands

In Site Region 5E, partial cyclic cuts in tolerant hardwood stands have produced basal area increments of 0.43 to 0.59 m^2/ha/yr (McLean 1987c) and volume increases of 3.8 m^3/ha/yr (Berry 1981) in periodic growth (see Table 9).

In the U.S. studies, uneven-aged stands typically contain a net volume of 125 to 140 m^3/ha before cutting. Selection management has produced growth rates ranging from 0.46 to 0.76 m^2/ha/yr in basal area and from 0.38 to 4.16 m^3/ha/yr in volume in periodic harvests, depending on cutting cycle and stocking level (see Table 10). Johnson (1984a) noted that cull levels were reduced progressively over three cutting cycles of seven years each from initial values of 25 per cent down to 12 per cent after 21 years, while the volume of grade 1 growing stock increased by 8 per cent. Harvested volumes increased at each cycle (from 0.74 to 1.22 m^3/ha/yr), while cordwood volumes decreased accordingly.

2.6.2.2 Even-aged Stands

Love et al. (1972) and Morawski (1971) considered their database to represent overstocked stands and suggested that productivities shown in their normal yield tables might be increased by a factor of two by the application of proper silvicultural techniques.

From the data in Table 9, tolerant hardwood stands managed on an even-aged basis in Ontario may be expected to produce from 0.38 to 0.96 m^2/ha/yr of basal area and 2.75 to 5.20 m^3/ha/yr of volume, depending on geographic location, species composition, and stocking levels. McLean (1987a, 1987b) found production rates of 0.40 to 0.75 m^2/ha/yr in basal area and periodic volume increments of 1.6 to 3.3 m^3/ha/yr for thinned hard maple stands in Site Region 5E. Working in Site Region 6E, Ellis (1971) measured basal area growth of 0.6 to 1.0 m^2/ha/yr in stands composed of hard maple, white ash, and black cherry thinned conservatively. Jaciw (1986) noted productivity rates of 3.8 to 5.2 m^3/ha/yr, depending on stocking level, for similar mixed stands in Site Region 6E. In the American studies (see Table 10), basal area growth ranged from 0.26 to 0.80 m^2/ha/yr, while volume production varied from 1.50 to 3.76 m^3/ha/yr, again depending on variables similar to those in Ontario. Jacobs (1968) reported that in hard maple stands clearcut 30 years previously, basal area at ages 0, 10, 20 and 30 years after treatment was 0.80, 2.75, 16.23, and 24.13 m^2/ha, respectively. Mean annual net growth for the 30-year period was 3.78 m^3/ha/yr, while the periodic growth from year 25 to year 30 was 7.42 m^3/ha/yr.

In summary, for hard maple at least, early yields (up to 40 years) in selection cuttings (uneven-aged) are about 25 m^3/ha more than from even-aged clearcuts; however, annual increments in the even-aged stands will surpass selection stands later in the rotation. In the long run, yield should not differ greatly between the two systems (Jacobs 1968).

TABLE 9: Comparison of Productivity Rates* for a Variety of Managed and Unmanaged Tolerant Hardwood Stands in Ontario

Source	Location	Species	Age Years	Managed Stand Increment				Unmanaged Stand Increment +			
				Basal Area		Yield		Basal Area		Yield	
				M^2/HA/YR	FT^2/AC/YR	M^3/HA/YR	FBM/AC/YR	M^2/HA/YR	FT^2/AC/YR	M^3/HA/YR	FBM/AC/YR
Plonski (1981)	Ontario	TH	150					0.20 - 0.25	(0.87 - 1.1)	1.23 - 1.89	(98 - 151)
Heeney (1974)	SR6E (E)	TH	120							(1.20)	96
Heeney (1974)	SR6E (W)	TH	100							(2.04)	163
Jaciw (1986)	SR6E (W)	TH	55	0.59 - 0.66	(2.57 - 2.87)	3.8 - 5.2	(303 - 415)	0.11	(0.48)	1.1	(88)
Ellis (1971)	SR6E (W)	TH	35 - 125	0.6 - 0.96	(2.61 - 4.18)						
Love et al. (1972)	SR7E,6E,5E	Mh,Be>80%	50							2.45 - 3.64	(196 - 291)
Love et al. (1972)	SR7E,6E,5E	Mh,Be<50%	50							3.01 - 4.41	(240 - 352)
Bebyn (1983)	SR5E (S)	By	38 - 53			2.75	(220)			1.7	(136)
McLean (1987a)	SR5E (S)	Mh	60 - 80	0.38 - 0.76	(1.65 - 3.31)						
McLean (1987b)	SR5E (S)	Mh	45	(0.71)	3.1			(0.35)	1.54		
Kershaw (1987)*	SR5E (N)	Mh	EVEN			3.3	(263)				
Kershaw (1987)*	SR5E (N)	By	EVEN			3.5	(279)				
Raymond and McLean (1984)	SR5E (S)	Mh	ALL					(0.37)	1.6	(1.52)	121
Ondro and Love (1979)	SR5E (S)	TH	ALL	0.23 - 0.25	(1.0 - 1.1)			0 - 0.03	(0 - 0.13)		
McLean (1987c)	SR5E (S)	Mh	ALL	0.46	(2.0)						
Berry (1981)	SR5E (S)	TH	ALL			3.8	(303)				

* Numbers in parentheses () are soft conversions according to the following conventions:
Basal area: $m^2/ha/yr = (ft^2/ac/yr)/4.356$ (Bowen [1974]).
Gross merchantable volume: $m^3/ha/yr = [(fbm/ac/yr)/1000]*12.528$ (Algonquin Forestry Authority, personal communication).

\+ "Unmanaged" refers to either undisturbed stands or stands modified by harvesting without silvicultural prescription.

* Personal communication, Ontario Ministry of Natural Resources, Sudbury.

TABLE 10: Comparison of Productivity Rates* for a Variety of Managed and Unmanaged Tolerant Hardwood Stands in the United States

Source	Location	Species	Age Years	Managed Stand Increment				Unmanaged Stand Increment +			
				Basal Area		Yield		Basal Area		Yield	
				M^2/HA/YR	FT^2/AC/YR	M^3/HA/YR	FBM/AC/YR	M^2/HA/YR	FT^2/AC/YR	M^3/HA/YR	FBM/AC/YR
Jacobs (1968)	Lake States	Mh	30	(0.80)	3.5	(3.76)	300				
Leak (1961)	New England	TH	40 - 60	(0.28 - 0.53)	1.2 - 2.3						
Solomon and Leak (1969)	New England	By	110	(0.26)	1.14	(1.50)	120				
Solomon and Leak (1969)	New England	By	147					(0.2)	0.85	(1.13)	90
Gingrich (1971)	Central States	Or	90			(2.03)	162			(1.27)	101
Johnson (1984a)	Michigan	TH	ALL			(1.49 - 1.73)	119 - 138				
Crow, Jacobs, Oberg and Tubbs (1981)	Lake States	Mh	ALL			(1.68 - 3.14)	134 - 251				
Jacobs (1968)	Lake States	Mh	ALL	(0.57)	2.5	(3.13 - 5.01)	250 - 400				
Scholz and Trenk (1959)	Wisconsin	Or,Mh	ALL			(0.38)	110				
Temple, Nyland and Crawl (1987)	New York	Be	ALL							3.0	(239)
Temple, Nyland and Crawl (1987)	New York	Mh,Be	ALL							6.1	(487)
Temple, Nyland and Crawl (1987)	New York	Mh,By,Be	ALL							3.9	(311)
Mader and Nyland (1984)	New York	TH	ALL	(0.64 - 0.76)	2.8 - 3.3	(3.96 - 4.16)	316 - 332				
McCauley and Trimble (1975)	Appalachians	TH	ALL	(0.46 - 0.53)	2.0 - 2.3	(3.12 - 4.82)	249 - 385				

* Numbers in parentheses () are soft conversions according to the following conventions:
Basal area: $m^2/ha/yr = (ft^2/ac/yr)/4.356$ (Bowen [1974]).
Gross merchantable volume: $m^3/ha/yr = [(fbm/ac/yr)/1000]*12.528$ (Algonquin Forestry Authority, personal communication).

\+ "Unmanaged" refers to either undisturbed stands or stands modified by harvesting without silvicultural prescription.

2.6.3 Simulation of Stand Development and Yield

In recent years, the use of normal yield tables with their inherent difficulties in defining normality and in its lack of clear relationship to managed stands, has given way to the use of simulation modelling techniques, which offer diversity, flexibility, and the opportunity for innovation (Moser 1980). An impressive range of applications is demonstrated in the proceedings of a recent IUFRO conference (Ek et al. 1987).

Many of the well-known published models have been developed for the THWG or offer methodologies that may be applicable to it. They range from comprehensive timber management strategy models (Shifley 1987, 1982; Brand 1981), to those for individual species of oak (Hilt 1985a), and mixed hardwoods (Marquis 1986), integrated ecological models (Rennolls and Blackwell 1986; Kimmins and Scoullar 1984; Aber et al. 1982; Botkin et al. 1972), multiple-resource models (Ffolliott et al. 1984), and economics of silviculture (Mitchell 1988).

Growth and yield models for the THWG are available for even-aged situations (Solomon and Leak 1986), uneven-aged conditions (Boothby and Buongiorno 1985; Hansen 1984; Raymond and McLean 1984; Moser et al. 1979), and for variable conditions (Solomon et al. 1987; Ek and Monserud 1979).

Even-aged models develop yield estimates as a function of stand age, while models applied to uneven-aged situations use functional relationships between yield and tree size distribution. In Ontario, two modelling systems have been developed from uneven-aged permanent-sample-plot data. Of special interest is that of Raymond and McLean (1987, 1984), which is based on comprehensive historical growth data from partially cut tolerant hardwood stands in Site Region 5E, and is appropriate for use in managing hard maple under the selection system. Tests indicate good accuracy (less than 10 per cent error) for projections of stem frequency, basal area, and volume over cutting cycles up to 15 years long.

A second projection system has been developed by Miller and Woods (1989). Based on a more limited database, it is applicable primarily to unmanaged, undisturbed hard maple stands, each showing a relatively small range of ages, in Site Regions 5E and 6E. These stands are primarily "second growth," having developed after severe disturbances occurring during the past 100 years. Note that while this provisional model gives good prediction accuracy (less than 15 per cent error) when applied to stands similar in nature to the original sample (i.e., undisturbed second growth), it was not designed for and is not recommended for conventional uneven-aged conditions or for stands managed under the selection system.

2.7 Genetics

Many species in the THWG show evidence of racial variation, especially in terms of "photoperiodic" or geographic ecotypes. For example, Kriebel (1957) established that hard maple

comprised three ecotypes, with the northern one exhibiting better apical dominance and resistance to winter injury but greater susceptibility to drought and leaf insolation injury, compared to more southerly ecotypes. Other characteristics are related to "clinal" or continuous trends over the species' range. Both yellow birch and hard maple, for example, show such a correlation in dates of initiation and cessation of growth and leaf abscission. This variation emphasizes the importance of using appropriate seed-zone sources for artificial regeneration.

Overviews of some genetic features of THWG species are found in Kriebel and Gabriel (1969) and Kriebel (1957) for hard maple; Wearstler and Barnes (1977) and Clausen (1973) for yellow birch; Gall and Taft (1973) and Cech (1971) for red oak; Wright (1944) for white ash; Pitcher (1982) for black cherry; and Fowells (1965) for all seven species.

2.7.1 Tree / Stand Improvement Strategies

The effect of a silvicultural activity in the forest is influenced by the interaction of genotype and environment, which gives rise to observable or phenotypic variation. All characteristics of trees are controlled to varying degrees by heredity (e.g., apical dominance), and some traits can be modified by environmental manipulation (e.g., in controlling the incidence of permanent stem forks by maintaining sufficient stand density to promote self-pruning).

Natural regeneration and stand manipulation in terms of phenotypic characteristics should be emphasized in the genetic management of the tolerant hardwoods. This concept differs from the genetic improvement program developed for Ontario's conifers (OMNR 1987d). Although this approach provides a less effective means of using the genetic differences among trees, genetic manipulation of the existing forest can be effected in the natural regeneration of forests, and in intermediate treatments such as thinning and improvement cuttings.

Harvesting desired species from mixed stands while leaving only the undesired species results in changes in forest productivity and timber quality. "Selective" harvesting (high-grading), which is not to be confused with harvesting under the "selection system," is rarely considered in genetic terms, but the potential negative impact on the genetic constitution of the forest stand is tremendous (Maynard et al. 1987).

The two most serious forms of "dysgenic" activities (i.e., changes detrimental to the genetic quality of future generations) as applied to the tolerant hardwood stands of Ontario are noted below:

- Diameter-limit cuts, which target the fastest-growing trees within a stand, those that in fact have survived the process of natural selection and have the potential to produce-higher quality offspring (Wilusz and Giertych 1974).

- High-grade harvesting for selected species or products, which leaves less desirable species to occupy the site (Zobel and Talbert 1984).

One or two generations of dysgenic selection will not result in future stands that are totally degraded genetically. In a naturally regenerated stand, the poorer-growing, non-competitive, pest-susceptible genotypes will tend to be eliminated and the resultant stand can be of satisfactory quality. However, three or more generations of dysgenic selection can result in "minus-type" stands (Zobel and Talbert 1984).

If sufficient acceptable growing stock remains to warrant further management under the selection system, the stand may be salvaged and made productive with proper regard given to genetic principles and the silvical requirements of the residuals. These considerations can be made only during a well-planned and well-implemented tree-marking program during which the following phenotypic characteristics are recognized (OMNR 1983):

- tree vigour as indicated by external bark and crown appearance;
- freedom from serious defects.

Genetic gains realized through management of the existing stand are less than those resulting from the planting of improved nursery stock, but these gains can be obtained quickly at minimum cost. Regeneration from seed, leaving the best-quality trees as seed producers, will provide the following benefits (Zobel and Talbert 1984):

- progeny that are well adapted to the site;
- improved tree form (which is usually highly heritable);
- increased or improved resistance to pests.

Gross total volume gains resulting from genetic improvement of the properly marked and harvested stand will likely be small since this characteristic is probably low in heritability (Kriebel and Gabriel 1969). Nevertheless, significant gains in net merchantable volume and quality will be realized through proper spacing of the trees of highest potential and reducing the cull factor in the stand.

2.7.1.1 Regeneration from Sprouting Species

Genetic improvement of any species will not occur when regeneration arises from sprouts of trees (as with red oak or white ash) that are already established, since the offspring are genetically identical to the parent tree (clones, in effect). Little can be done to improve the genetics of these stands beyond later crop-tree selection and thinning.

2.7.1.2 Thinning

The genetic potential of a tree can never be fully realized when it is growing in an overstocked situation. An effective thinning program can control spacing and competition, species composition, and the selection of individual trees of greater potential in the residual stand.

Genetic improvement of the existing stand will depend totally on the tree-marker's ability to identify and rank visible phenotypic characteristics of each tree being managed (Sonderman 1979; Sonderman and Brisbin 1978; Boyce and Carpenter 1968; Clausen and Godman 1967; Rudolf 1956). Criteria for phenotypic selection are as follows:

- Quality-related characteristics:
  Straight stems, round boles with low taper, straight grain, good self-pruning, apical dominance, large branch angle, and small branch diameter. Internal defect is often a function of history—a result of mechanical injury, for instance. Trees with such defects may be maintained in the residual stand if other characteristics are phenotypically superior to other individuals in the stand.

- Growth-related characteristics:
  Tree height, stem diameter, and growth rate as well as volume, length, diameter, and density of the crown.

Exceptions to the application of these criteria may occur in order to achieve other objectives, such as the maintenance of wildlife habitat (see Section 2.8, "Wildlife Considerations").

2.7.2 Potential Breeding Strategy

In any future breeding program for one or more of the tolerant hardwood species, the principal objective will be to obtain improved growth while preserving existing superiority over other individuals of the same species with regard to wood properties. In species with intermediate shade tolerance, suppression-induced mortality tends to eliminate the less-efficient, slower-growing components of a stand. Kriebel (1963) notes, however, that there is a relatively low degree of selection pressure against slow-growing hard maple individuals, partly because of their shade tolerance and elastic response to release. Breeding should concentrate on high-value products, especially lumber and veneer (Morgenstern 1979; Clausen 1973; Cech 1971; Kriebel and Gabriel 1969). It may be feasible in future to breed for such features as figured grains (e.g., curly, wavy, birdseye), etc., but this is impractical at present.

Generally, improvement of sawlog species concentrates on increasing the quality of individual trees rather than the gross volume, whereas improvement of fibre species is aimed mainly at increasing yields per hectare (Calvert 1979). Artificial regeneration with improved stock of species of intermediate tolerance may involve planting 125 to 250 potential crop trees per hectare, with the requisite site preparation and tending to ensure optimal development. Costs per tree will be high and conversion costs per hectare will be moderate.

Farmer (1973) suggests that a ranking of species that could warrant breeding-program investment should be based on the consideration of several factors, including the following:

- value increment rate;
- predominance in the existing forest;

- value for uses other than timber production;
- ease of establishment;
- area available for artificial regeneration;
- likelihood and cost of breeding success;
- cost of producing improved stock.

Based on these criteria, red oak, yellow birch, and white ash appear to be likely candidates for tree improvement based on artificial regeneration programs. Marquis (1973) considers black cherry to be an attractive candidate for tree improvement investment in the northeastern United States but that red oak would require large genetic gains to justify costs. Seeding is the optimal means of effecting these artificial regeneration programs, with planting the secondary means. Technology for regeneration of yellow birch through direct seeding is already in place. Similar technology for red oak and white ash has not yet been developed.

A small yellow birch gene pool reserve has been established at Maple, Ontario, and could be used to advantage in an artificial-regeneration-based tree improvement program. Little work has been done to date on red oak.

Vegetative propagation has been accomplished from stem cuttings for yellow birch (Hannah 1988b), black cherry (Farmer and Besemann 1974), hard maple (Morsink and Jorgensen 1974; Gabriel et al. 1961), and red oak (Isebrands and Crow 1985). Propagation by air-layering has been achieved for hard maple by Cunningham and Peterson (1965). These techniques could be useful in developing planting stock for any future genetically improved clonal material.

2.8 Wildlife Considerations

From a wildlife habitat perspective, diversity is the key to an overall vegetation management strategy. In general, maintaining a variety of habitat types, including riparian (shoreline) zones, snags, and downed timber with a mixture of species, stand sizes, and ages, benefits most wildlife. It is, however, impossible to accommodate the needs of all wildlife in a specified area. Habitat diversity can be optimized when several forest types or working groups are managed simultaneously, especially if management techniques and cutting regimes differ. Although some species of wildlife benefit from little or no man-made intervention in the forest environment, many others do benefit from intervention that creates or augments vegetative diversity, provided that certain critical habitat needs are protected (Thomas 1979).

Wildlife affect, and are affected by, their habitat. An increase in the quantity or quality of habitat will normally enhance the productivity, condition, and survival of wildlife. Similarly, a decline in habitat will generally cause a reduction in the well-being and ultimately in the numbers of

wildlife in the area affected (e.g., the loss of winter shelter will affect white-tailed deer). In some cases, wildlife such as white-tailed deer can adversely affect their habitat by overbrowsing, which often leads to population decline (Marquis and Brenneman 1981). Overbrowsing can also cause a reduction in the regeneration of commercially valuable tree species. These effects may be good or bad, depending on the resource managers' expectations and established objectives.

Individuals and populations of wildlife exist in fluctuating equilibrium with their surroundings and are influenced by such interrelated factors as the vegetation community, water, weather, predators, disease, hunting, etc. To assist in integrating the management of timber and wildlife resources, provincial guidelines and resource manuals for habitat management for moose, deer, and several other wildlife species have been prepared by the OMNR Wildlife Branch. These detailed guidelines are referenced specifically in the following sections and should be used as an integral part of the management and operational planning process.

Historically, the THWG in Ontario has been harvested primarily by partial cutting. Some large areas were clearcut about the turn of the century, to provide material for fuel and the production of charcoal and wood distillate products. The first hardwood sawlog cuts were usually high-grades for yellow birch veneer logs, in the late 1930s and early 1940s, followed by maple high-grading. Management has progressed from diameter-limit logging to the more regulated selection and shelterwood systems in common use today.

Partial cutting has produced little change to the habitat of most wildlife and usually has had little impact on wildlife populations, except where limited critical habitat (such as hemlock wintering areas for white-tailed deer) was removed or altered. Management that creates optimum white-tailed deer habitat generally benefits a large variety of other wildlife. In some situations, however, this does not apply or is only partly true.

More than 300 vertebrate species (including 44 mammalian, 230 avian, and 28 reptilian and amphibian species) are found within the THWG in Ontario (Strickland and Rutter 1983; Strickland et al. 1980; OMNR 1976). In this guide, the following groups of wildlife are considered:

- large mammals, i.e., moose, white-tailed deer, and black bear;
- furbearers;
- birds, including passerines, raptors, and game birds;
- others, including small mammals, reptiles, and amphibians.

A brief synopsis of habitat and management requirements within the THWG for these wildlife species is presented in the following sections. A summary of relevant concerns and timber management strategies is presented in Table 11.

TABLE 11: Wildlife Habitat, Timber Management Concerns, and Timber Management Strategies within the THWG*

Selected Species	Wildlife Habitat	Timber Management Concerns	Timber Management Strategies to Maintain/Enhance Habitat
Deer	Conifer shelter.	Loss of shelter or potential shelter.	Cutting within yards and yarding complexes to maintain and/or enhance shelter/food components and ratios.
	Permanent openings.	Loss of permanent openings.	Maintain existing grassed openings; create new cool season forage by seeding logging trails and landings with grass/legume mixtures where appropriate.
	Second-growth deciduous forest.	Maintenance of early successional forest.	Where possible, design cut to encourage early successional forest and adequate levels of browse production.
		Loss of mast producers through timber management activities.	Maintain mast-producing species in adequate numbers.
	Special feeding areas.	Protection of special feeding areas.	Protect special feeding areas via areas-of-concern designation.
Moose	Conifer shelter-escape.	Loss of winter shelter.	Maintain hemlock component in clumps or patches at least 3 ha in size, where appropriate as winter cover. Limit cover-to-cover distance if clearcut.
	Cover and calving sites.	Disturbance of aquatic feeding areas, mineral licks, and calving sites.	Protect calving sites, mineral licks, and aquatic feeding areas with area-of-concern status.
	Browse and forage.	Provision of early successional forest.	Where possible, design cuts to stimulate early successional regrowth.
Black Bear	Mixed habitat including riparian forests, mature upland mixedwoods for den sites and feeding.	Loss of den sites.	Cuts that result in high edge/area ratio will benefit bear. Protect known den sites.
		Loss of hard mast crops (e.g., acorns, beechnuts).	Retain some mature mast-producing trees.
	Early successional areas for feeding.	Some food supplies enhanced by cutting (early successional forest).	
Marten, Fisher	Immature and mature conifers and mixedwood stands.	Loss of THWG hemlock component that can provide winter cover.	Protect hemlock patches within hardwood stands.
			Maintain or enhance hemlock component of hemlock or hemlock/spruce stands.
	Den sites in tree cavities in THWG.		Maintain at least 50% of canopy in hardwood selection cuts.
			Maintain up to six snags or potential snags/ha.
Lynx, Fox, Wolf	Early successional areas, mixedwood stands of various ages.	Regeneration of deciduous and herbaceous vegetation in cutover will improve small-mammal populations and benefit their predators.	Producing a mosaic of cut and uncut stands will maximize edge effect and provide mix of cover and early successional feeding areas.

*Reference should be made to individual guidelines for further concerns, the context of these concerns, as well as explanations of the allowable refinements of the guidelines.

TABLE 11 (cont.)

Selected Species	Wildlife Habitat	Timber Management Concerns	Timber Management Strategies to Maintain/Enhance Habitat
Beaver, Otter, Mink, Raccoon	Riparian areas.	Loss of cover, including snags, stumps, woody debris, deciduous and herbaceous vegetation.	Protect shorelands depending on slope and soil texture. Some cutting to shore will enhance beaver habitat.
Grouse	Upland mixedwoods and hardwoods.	Nest sites and feeding areas. Winter roosting sites.	Maintain or create a variety of stand types, ages, sizes, and openings.
Osprey	Riparian areas. Nest in dead or open-topped trees. Prey on fish.	Loss of current and potential nest sites. Habitat disruption and loss near nest site. Osprey nesting period: approximately April 15 - September 1. Herons nesting period: approximately April 1 - August 15. Bald eagle nesting period: approximately February 15 - September 1. Peregrine falcon nesting period: approximately March 15 - September 1.	No timber management activities in immediate vicinity (^) of nest at any time. Modified cutting possible near nest (^) during non-sensitive period.
Herons	Riparian areas.		
Bald Eagle (endangered species)	Riparian areas. Nest in very tall trees.		
Peregine Falcon (endangered species)	Nest on cliff ledges, especially near water. Prey on small birds.		
Other Birds	All combinations of vegetation provide habitat for birds.	Loss of nest sites, feeding areas. Disturbance during nesting.	Maintain/create a range of stand types, ages, sizes. Provide riparian forests, snags, and large blocks of mature pure and mixedwood forest.
Small Mammals	Variety.	Provision of a variety of habitats.	A variety of silvicultural systems and management strategies.
Amphibians and Reptiles	Riparian areas.	Protection of riparian habitat.	Recommendations contained within *Timber Management Guidelines for the Protection of Fish Habitat* (OMNR 1987h) ensure protection of most riparian areas and, therefore, most herpetofaunal habitat.

(^) Refer to individual guidelines and resource manuals for further concerns, the context of these concerns, and explanations of the allowable refinements of the guidelines.

2.8.1 Large Mammals

2.8.1.1 White-tailed Deer

The THWG provides significant habitat within the current range of white-tailed deer in Ontario. The working group contributes heavily to the food and cover requirements of deer. The food contribution can be significant on both winter and non-winter range. Most of the commercially important tree species involved in this working group are sources of high-quality winter browse (beech is the principal exception). Both commercial and non-commercial broad-leafed plants provide protein-rich succulent growth during spring and summer. Beech and oak contribute valuable mast during autumn and early winter.

Throughout much of their range, deer show a decided preference for hemlock as winter cover. This species is perhaps the most limiting habitat component for deer, particularly in areas that traditionally experience deep snow and extreme cold (such as Algoma and the western part of Algonquin Region). The exceptional capacity of hemlock to intercept snow and its thermal advantage is well documented. In eastern Ontario, white pine, hemlock, and cedar are the principal cover species. Spruce and fir types can also be important locally.

The tolerant hardwoods and all other working groups should be managed in concert, if the requirements for food, cover, and water are to be optimized. For vegetation management to benefit deer, consideration should be given to developing a high diversity of plant species of different ages and appropriate quantities interspersed throughout their range. Provincial guidelines for providing deer habitat are given in *Timber Management Guidelines for Providing White-Tailed Deer Habitat* (OMNR 1987f). These guidelines focus on the protection and enhancement of specific habitat components, such as:

- conifer shelter;
- permanent openings;
- areas of second-growth deciduous forest;
- special feeding areas.

Both winter and summer range are important. While the amount and condition of winter range may be the factor exerting the greater direct limiting influence on population numbers, non-winter range will largely determine the condition of deer entering these yards in late fall. Management of both components is, therefore, desirable.

Management of Yards and Yarding Complexes

Habitat management should be aimed primarily at providing abundant woody browse in areas accessible to wintering deer. Deer seek out conifer cover during winter because it provides thermal protection and reduces the snow depth, thus facilitating travel. Both these benefits

reduce winter stress on the animals by slowing the depletion of body energy reserves. Browse occurring within 100 metres of adequate conifer cover (greater than 60 per cent canopy closure) is desirable (OMNR 1987f). Cutting of hardwoods in and near conifer shelter should employ small clearcuts (up to 2 ha) or the shelterwood system. The objective of these cuts is to maximize available browse while protecting the cover component. Late fall and winter cutting provide immediate browse, and logging trails are used by deer as travel and escape lanes. Small clearcuts of hardwoods on west and south slopes adjacent to cover are best. Cutting within the conifer component of yards or potential yards should be restricted to canopy adjustment for enhancement of cover and food. In both hardwood and softwood components, the timing and intensity of the cut should be tailored to current or potential use by wintering deer.

Management of Non-Winter Range

The seasonal food requirements of deer are well documented and can be achieved using approved silvicultural systems. Clear cutting of small blocks (10 to 50 ha) creates diverse plant associations and maximum edge and is therefore the preferred system for creating deer habitat. Strip shelterwood, uniform shelterwood, and selection are the other options, in decreasing order of preference.

Tolerant hardwoods contribute significantly to provision of browse. Regeneration of late successional species is accomplished with shelterwood and selection management, while early successional species are encouraged most under clear cutting regimes. Clearcuts and strip shelterwood maximize species diversity and edge, whereas uniform shelterwood creates moderate diversity of species, but provides less edge. Single-tree selection in comparison to the above systems creates the least desirable habitat as plant diversity is limited to shade-tolerant species. As well, total stems per hectare (of commercial species and others) can be less abundant under the selection system. These apparent shortcomings can be corrected to a large extent by incorporating group-selection management within the single-tree selection system. The advantages of doing so are as follows:

- The intent of the timber management objective of single-tree selection can be achieved.
- Regeneration of a larger variety of plant species will occur within openings created by group-selection harvesting. This reproduction will include moderately tolerant commercial species such as yellow birch, black cherry, white ash, oaks, red maple, and numerous non-commercial trees, shrubs, bushes, herbs, and grasses, most of which provide good forage.
- The single-tree selection system is the preferred system for regenerating beech, while group selection can contribute significantly to the regeneration of red oak. Both are valuable mast producers.
- Although abundance and variety of regeneration are less under the selection system, regeneration remains available as forage virtually forever because of short cutting cycles (10 to 20 years).

Mast-producing areas and mineral licks are special feeding areas. Provincial guidelines recommend maintenance of good mast-producing trees within 1 km of yards and management that ensures the integrity of mineral licks where they can be identified. The importance of permanent openings to deer is well documented. Such areas provide cool-season forage of grasses and herbs that are critical to recovery in spring and fat deposition in fall. Where tolerant hardwoods occur in extensive tracts, such areas can be uncommon and should be maintained. The extensive network of roads and landings created by logging provides opportunities for seeding of grasses and grass/legume mixtures.

2.8.1.2 Moose

Moose are important big-game animals inhabiting the THWG, especially in the northern climatic zones, including the Algoma-Lake Superior Zone and the Lake Huron-Algonquin Zone (Bruce and Heeney 1974).

Cutting in the THWG generally produces good habitat if it causes sufficient disturbance to stimulate early successional growth without removing conifer cover used for shelter. Also, it must maintain the integrity of aquatic feeding areas, calving sites, and mineral licks (normally protected by areas of concern).

The selection and shelterwood systems may not fully accomplish this objective; modifications to the recommended silvicultural system may therefore be necessary where the creation of moose habitat is a management objective. Refer to *Timber Management Guidelines for the Provision of Moose Habitat* (OMNR 1987g) for more information.

2.8.1.3 Black Bear

The black bear is an important big-game animal throughout the THWG. Bear thrive in a diverse forest landscape that provides food, shelter, den sites, and escape cover (Kolenosky 1981). The presence of mast-bearing species (e.g., beech and oak) improves bear habitat. Since large hollow trees, snags, and hollow logs are often used as den sites, a few should be left for this purpose whenever possible. In general, the guidelines in *Timber Management Guidelines for Providing White-Tailed Deer Habitat* (OMNR 1987f), if followed, will produce good bear habitat providing that consideration is given to retention of den sites.

2.8.2 Furbearers

2.8.2.1 Terrestrial Furbearers

The major terrestrial furbearers associated with the THWG are fisher, marten, wolf, and fox.

Marten and Fisher

Both marten and fisher are strongly associated with mature conifer or mixed forest. Their principal dependency on the tolerant hardwoods is for den sites in tree cavities and for foods, which include small mammals, snowshoe hare, porcupine (for fisher), birds, insects, mast, and berries (Allen 1983). The hemlock component within the THWG can provide winter cover for both species. In general, management within the working group that enhances deer habitat will benefit fisher. Marten benefit from protected blocks of mature coniferous forest, selection cuts that maintain at least 50 per cent of the forest canopy, and small strip or shelterwood cuts that encourage conifer growth (Allen 1982).

Lynx, Fox, Wolf, and Coyote

To provide habitat for such predatory furbearers as lynx, fox, and wolf, management techniques that create early successional vegetation beneficial to prey species is preferred (OMNR 1986a). Lynx are uncommon throughout the working group but do occur at the northern limits. Fox and coyote are common throughout; the timber wolf is found less frequently, but ranges throughout the working group with the exception of the more southern and eastern reaches.

Foxes and wolves tolerate a wide range of habitat conditions, provided that food species are present. Management that creates high-quality deer habitat normally benefits predatory furbearers.

2.8.2.2 Wetland-Associated Species

The major wetland-associated furbearers are beaver, mink, otter, and raccoon. *Guidelines for Providing Furbearer Habitat in Timber Management* (OMNR 1986a) outlines the following recommendations in detail:

- To enhance beaver habitat, forest openings created by cutting practices should be large enough to promote early successional growth. Block clearcuts or strip cuts should be at least 40 m wide.

- To maintain habitat for raccoon, mink, otter, and their associated prey species, harvesting and subsequent timber operations should maintain structural diversity such as snags, woody debris, and downed logs within wetlands and along shorelines.

In general, management strategies for tolerant hardwoods have little impact on wetland furbearers. This is due, in large measure, to the normal silvicultural practices a.d specialized management techniques and reserves set aside for wildlife, fisheries, or tourism concerns. There is a negative impact on beaver where management or protection of areas of concern maintain older or late successional forest in riparian areas.

2.8.3 Birds

Although the effects are site- and species-specific, avian communities often benefit from forest disturbance. There is normally an increase in diversity and abundance of birds after logging, although the species mix may change (Webb et al. 1977).

In general, providing habitat diversity is basic to sound wildlife management. However, specific rare or declining species may require special management techniques to meet their needs (OMNR 1984a).

There are no species of birds found only in small forest tracts. Several species, however, are found only in large tracts of mature or overmature forests, including the THWG. These "area-sensitive" species include some of the hawks, owls, woodpeckers, and warblers. For some, even disturbances as light as that created by selection silviculture can be deleterious, and such possible effects should be considered at the planning stages of timber management. Refer to *Habitat Management Guidelines for Warblers in Ontario's Northern Coniferous Forest, Mixed Forest or Southern Hardwood Forests* (OMNR 1984a) for more information.

2.8.3.1 Passerines

More than 200 passerine (perching) species are found within the THWG. Passerine birds act as important components in the natural biological control of insect pests at endemic levels. Although the primary benefit is prevention of epidemics, they may in some circumstances exert major depressing influences on outbreaks (OMNR 1984a). It is impractical to describe habitat requirements for all passerines. Generally, for most passerine birds, the application of the guideline *Timber Management Guidelines for Providing White-Tailed Deer Habitat* (OMNR 1987f) along with the protection of riparian habitat (normally accomplished through area-of-concern shoreline modified management) will protect and benefit most species.

The presence of dead or dying trees suitable for cavity excavation is the single most important factor limiting the number of cavity-nesting birds, including such species as pileated woodpecker, brown creeper, black-capped chickadee, wood duck, and northern saw-whet owl (OMNR 1984b). Excavations by the pileated woodpecker are of significance to a number of bird and non-bird cavity users since most prefer old woodpecker holes to other natural cavities. Management that removes all hard and soft snags from stands is detrimental to pileated woodpeckers and therefore to most cavity-nesting birds and other secondary users. As with most passerine birds, much of the critical habitat is found in riparian zones, which are often protected as areas of concern. Such is the case with pileated woodpeckers, whose nest sites are typically within 50 m of a stream or lake. More information on the requirements of other cavity nesters is available in *Habitat Management Guidelines for Cavity-Nesting Birds in Ontario* (OMNR 1984b).

2.8.3.2 Raptors

Most of the raptors (birds of prey) in the province inhabit the THWG to varying degrees. Several species, including the bald eagle, peregrine falcon, osprey, northern goshawk, Cooper's hawk, red-shouldered hawk, red-tailed hawk, and kestrel (in cavities) and some of the owls—for example, the great horned, screech (in cavities), and saw-whet (in cavities)—prefer nesting in deciduous trees of this working group (OMNR 1984c). Although specific habitat requirements vary, most, if not all, of the forest-dwelling raptors display preference for nesting near riparian areas, and most are sensitive to disturbance during the nesting season (early April to mid-July depending on species, and early February for the great horned owl).

Generally, the protection of nesting sites and maintenance of productive riparian habitat are key elements to raptor maintenance. Certain species (for example, red-shouldered hawks) are more area-sensitive than other species and may warrant special consideration in timber management planning. Further information is available in *Habitat Management Guidelines for Ontario's Forest Nesting Accipiters, Buteos, and Eagles* (OMNR 1984c).

2.8.3.3 Upland Game Birds

The ruffed grouse is the principal upland game bird of the THWG. Grouse prefer early successional aspen forests with numerous openings to the habitat provided by tolerant hardwoods. Scattered conifer is desirable for winter roosting (OMNR 1979). Cutting regimes that create numerous, relatively small openings (rather than large clearcuts or single-tree selection) are preferable. Management of this working group to deer habitat specifications will create fair-quality habitat for grouse. For this species, however, the best habitat management potential exists in the poplar and white birch working groups.

2.8.4 Other Wildlife Species

Although there is relatively little knowledge concerning the effects of forestry practices on small mammals, several studies have documented broad responses of small-mammal communities to clear cutting. The evidence suggests that while there are site- and species-specific differences, both abundance and diversity of small mammals increase after logging, although the species using the area may change. Presumably, management prescriptions that open the canopy and produce a patchy forest will increase the overall abundance of small mammals and thus enhance the entire community of predators and prey (OMNR 1979). The effects of forestry practices on amphibians and reptiles are basically unknown. However, because most amphibians and reptiles depend on water bodies for at least part of their life cycle, protection of riparian habitat is beneficial and advisable. Guidelines for maintenance of fish habitat are outlined in *Timber Management Guidelines for the Protection of Fish Habitat* (OMNR 1987h).

2.9 Environmental Considerations

Class Environmental Assessment for Timber Management on Crown Lands in Ontario (OMNR 1987a) states that:

> Timber management operations can cause a variety of environmental effects. These effects can be positive or negative, short-term or long-term, direct or indirect, temporary or permanent, reversible or irreversible, or cumulative. The potential occurrence of any of the effects, their magnitude, and perhaps most importantly, the significance of the predicted effects, will vary between and within individual management units. Most negative environmental effects can be prevented or minimized through proper planning and implementation of timber management operations, or mitigated through application of effective remedial measures.

In Ontario, all potential macro-level environmental effects are discussed in the above document. Local effects are dealt with during the development of the timber management plan. Normal operational procedures, as outlined in this guide, will usually protect environmental values in areas where the THWG is being managed.

Environmental considerations for the timber management activities of road construction, timber harvest, forest renewal, and maintenance that are applicable to the THWG are discussed below.

2.9.1 Road Construction

Proper planning, construction, and maintenance of roads is essential. Where rough topography and fine-textured soils occur, particular care is required to minimize or prevent soil erosion. This is especially important because of the predominance of selection and shelterwood systems used in the management of the THWG; such systems require high-quality access due to frequent periodic use.

Considerations for the construction of forest access roads to minimize potential environmental effects are presented in *Environmental Guidelines for the Construction of Access Roads* (OMNR 1988).

2.9.2 Timber Harvest

The selection and shelterwood systems are recommended for the harvest of the THWG. The clearcut system (as defined in Section 3.1, "Silvicultural Systems") is restricted to areas with poor accessibility where the objective is conversion of the area to species of better quality, or to fibre products.

Application of the selection and uniform shelterwood systems ensures that continuous cover is retained on the harvested area. These systems minimize erosion and sedimentation. Nyland et al.

(1976) found in a study of strip, patch, and selection cuttings, that soil displacement averaged only 54 kg/ha harvested even after sustained heavy rainfall. Most soil that washed away did not leave the site. They concluded that there was only limited potential for erosion regardless of logging method.

The THWG is generally found on moderately fine-textured soils consisting of sandy loams and silty sands, which are moderately susceptible to compaction and rutting when excessively moist. Such compaction and rutting, if significant, can be minimized by harvesting in winter when the ground is frozen.

The amount of nutrients contained in harvested timber varies with species, age, soil conditions, and the intensity of the harvest. There is no evidence to indicate that conventional practices, particularly the selection and shelterwood systems, result in a significant loss of nutrients that will affect forest productivity (Clements 1973).

The amount of nutrients contained in the forest stand is relatively small in comparison to the total nutrient pool contained in the soil. The forest floor is important for the biochemistry and ecology of the tolerant hardwood forest, especially on acid substrates with a low mineral-nutrient supply. A high proportion of the available nutrients on such sites is localized in the organic matter of the forest floor, which tends to be maintained by litterfall (Heij and Leek 1981; Bormann and Likens 1979). Therefore, prompt re-vegetation of cutover will minimize nutrient loss (Hendrickson et al. 1982).

Logging may promote floral diversity in cases where substantial canopy openings are made or where a large proportion of basal area is removed. Such diversity of composition attracts a variety of wildlife species and in some cases improves habitat (Bell et al. 1974). However, management systems such as the selection system that are intensively species-selective and that involve modest removal of volume will minimize changes or trends to diversity in the forest flora (Randall and Sassaman 1979). Specific requirements and concerns for wildlife habitat in the THWG are addressed in Section 2.8, "Wildlife Considerations."

2.9.3 Renewal

Regeneration and establishment of a new forest crop in the THWG is largely accomplished through natural regeneration.

For tolerant hardwood species managed under uneven-aged conditions, little activity is required except to protect advance growth during harvesting by planning skidding activities. For hardwood species of intermediate shade tolerance, some seedbed preparation is usually required. This involves scarification, prescribed burning, or herbicide treatments to disturb litter and control competing vegetation.

Scarification, which occurs coincidentally with logging and may be augmented after cutting, disturbs the forest floor by breaking up leaf litter and reducing established vegetative compe-

tition. Ideal seedbeds are mixtures of humus and upper mineral soil horizons that retain sufficient nutrients to satisfy the relatively demanding hardwood species of the THWG.

Prescribed fire is used to eliminate leaf litter and established vegetative competition on a site. This may result in temporary elimination of some useful species, such as sugar maple, in order to successfully establish a less-tolerant valuable species such as yellow birch (Anderson 1982; Burton et al. 1969). Holowacz (1960), working in tolerant hardwoods in Algonquin Region, noted little change in soil nutrient or acidity after prescribed burning in the fall. While fire is not a nutrient-depletor in this context, its use on impoverished or very coarse-textured soils should be restricted (Clements 1973).

An alternative to prescribed fire for competition reduction prior to establishment of regeneration is the use of herbicides. Only herbicides registered for forestry application under the federal Pest Control Products Act and scheduled for use in Ontario under the Pesticides Act (Province of Ontario 1980) are available, and these are used only with ground application techniques at rates recommended in the *Guide to Chemical Weed Control* (OMAF 1988), which is updated annually.

2.9.4 Maintenance

In the THWG this usually takes the form of crop-tree selection and release treatments to maintain a free-to-grow status while at the same time ensuring adequate density to promote self-pruning (bole quality).

In some cases where free-to-grow status may not be achieved in the required time period, release from competition by the use of herbicides may be considered. This is done most frequently for the benefit of planted stock and is dealt with using ground application in strips or in shielded spray (see Section 3.5, "Stand Maintenance").

Fertilization as a management practice in the THWG cannot be recommended at this time.

Experimentation with forest fertilization in North America, including Ontario, has yielded generally conflicting results (Leech and Kim 1988; Stone 1986, 1980; Hannah 1985, 1973; Mroz and Shetron 1983; Ellis 1979; Safford 1973) and emphasizes the point that fertilization can improve growth and/or health only when nutrient deficiencies are properly diagnosed (Leech and Kim 1970; Swan 1969) and when effective, safe amendment prescriptions are developed (Lozano and Huynh 1989; Leech and Kim 1981).

3.0 MANAGEMENT PRESCRIPTIONS

The forest management process involves a sequence of integrated decisions that incorporates factors of site, silvics, forest structure, environment, wildlife, and economics, among others, and ultimately leads to a series of prescriptions for the harvest, renewal, and maintenance of a forest unit[5] over its rotation (see Figure 12).

In order to manage the diversified hardwood forest resource in a productive yet economically responsible manner, it is apparent that differential levels of treatment or investment will be necessary according to the nature of the forest, its site quality, its location, its potential economic contribution, and its complementary values for other uses. OMNR (1986g) has outlined four levels of forest investment:

- Extensive:
  An area is logged but no silvicultural treatment is applied. The area is regenerated by uncontrolled volunteer species, which may produce a new crop of lower value requiring a longer developmental period than in treated areas.

- Basic:
  Modified harvest-cutting methods may be used along with low-cost site preparation to provide a suitable seedbed and remove logging debris for natural or artificially seeded regeneration. Stocking of reproduction will be expected to be higher than with unassisted natural regeneration and species composition may be controlled to some degree but no subsequent tending is undertaken. Forest productivity is maintained, quality is improved and rotations may be somewhat shorter than in the Extensive level.

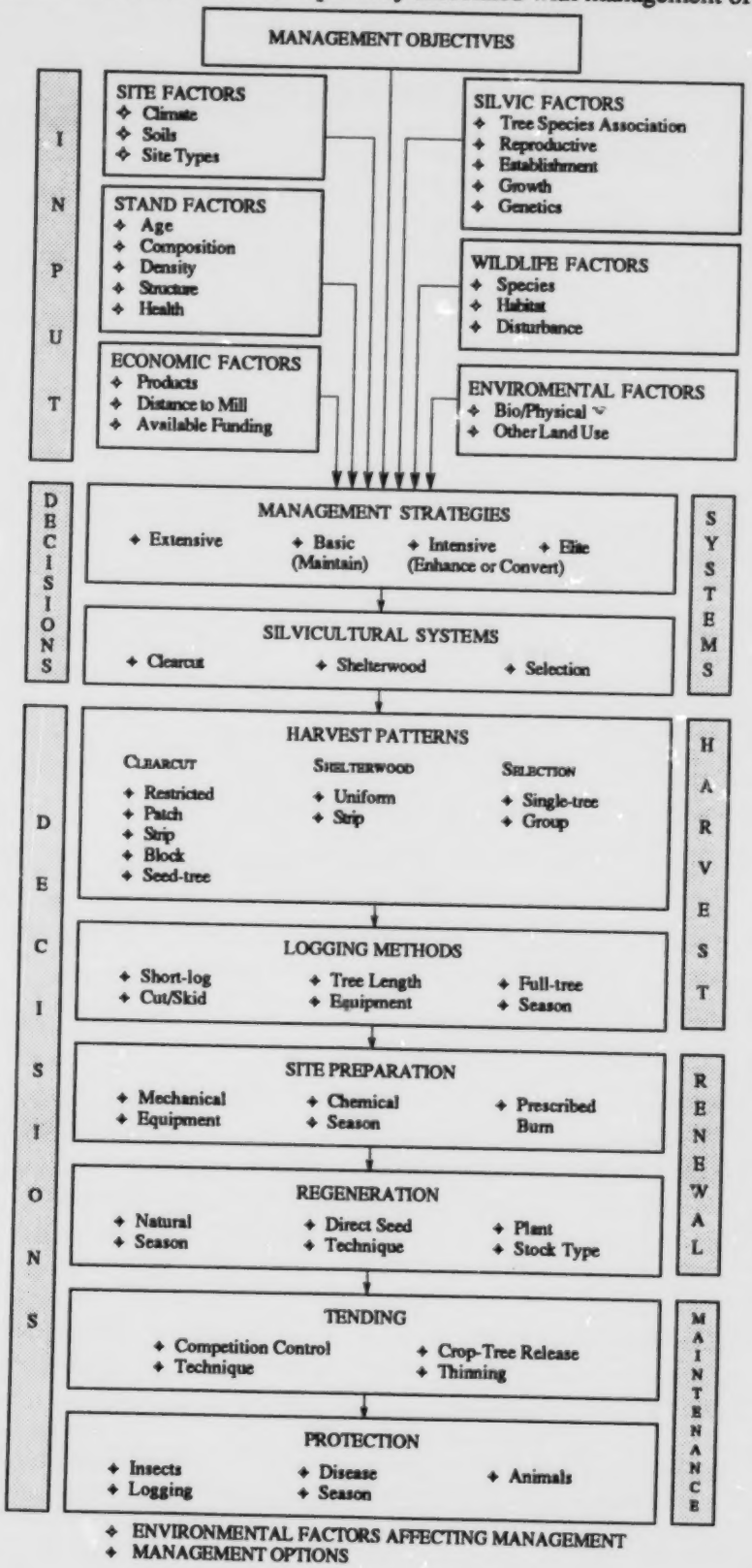
- Intensive:
  Better sites are selected and modified harvest cutting may be employed to assist regeneration establishment by means of site preparation and subsequent tending at least to the free-to-grow stage. Stocking objective for this intensive regeneration treatment is 70 per cent and subsequent shortening of the rotation and improved yield are anticipated.

- Elite:
  Higher investments are made on the most-productive sites. Site preparation is followed by planting with genetically improved stock, which is assisted by intensive cultivation (tending, thinning, protection) through to rotation age, which is significantly shortened. Stocking levels of desired species are expected to be 80 per cent and enhanced yields (up to 200 per cent of natural stands) may be anticipated. Lack of availability of genetically improved stock currently precludes this option for the THWG.

The main objective of Ontario's forest management policy is "to provide for an optimum continuous contribution to the economy of Ontario by the forest-based industries and to provide for other uses" (OMNR 1986d). However, growth in production is not synonymous with growth

[5] Forest unit: Any aggregate of forest stands managed under the same silvicultural system and rotation (OMNR, Forest Resources Branch Policy No. FR 15 02 01 PO [1988], *Forest Units*).

FIGURE 12: Silvicultural decision pathway associated with management of the THWG



in value, which is determined partly by the type of end-product, its consumer demand, and its scarcity of supply. A corollary of the objective might then be stated: "to maximize the economic value per unit volume of wood."

The THWG species, with the exception of beech and hemlock, have high unit-value (i.e., veneer, high-quality sawlogs), and because of the remanufactured nature of the products, also have a high value-added component and thus make a strong contribution to the economy. Such values justify the use of intensive levels of management when the growing potential and location of the site are suitable for quality production. In these situations, attempts would be made to bring the forest into a highly regulated state to maximize value growth. In other cases, perhaps more commonly on poorer sites, the level of management would be basic; that is, the value expectation would be lower (fibre or low-quality logs) and the silviculture would be less sophisticated. In yet other circumstances, the site may be converted to other, more appropriate species (e.g., softwoods) or dedicated to other uses (e.g., wildlife habitat). The management prescription would therefore recognize the stand site potential and the appropriateness of various investment levels in consideration of potential economic and use capability.

A useful overview of the status of THWG management in Ontario is outlined by Wray et al. (1985). Some applications of technology developed for forest management by OMNR staff may be found in the "Silviculture Note" series, and more recently, the "Silviculture Bulletin" series of reports published by Forest Management Branch.

3.1 Silvicultural Systems

A silvicultural system is a planned program of silvicultural treatments carried out during the entire "life" of a stand for the purpose of controlling the establishment, composition, and growth of the forest. The nature and intensity of application of its components (harvesting, regeneration, and tending) varies with accessibility, markets, the quality of the existing forest and its growth potential, site quality, and management objectives.

The THWG can be managed by either even-aged or uneven-aged silvicultural systems. The choice of the even- or uneven-aged method will be based primarily on the silvics of the species of interest, the initial state of the stand, and the type of product required. While conversion from one method to another is possible, and sometimes desirable, it is done at the expense of time. Only shade-tolerant species (such as hard maple, beech or perhaps white ash) may be managed under either method. However, those species with less shade tolerance (birch, cherry, oak) may be regenerated and managed only under even-aged methods.

Arguments supporting each method (Morriss 1968; Arbogast 1956) and both approaches (Tubbs 1968) have been put forward for hard maple. While the efficiency of even-aged methods has frequently been demonstrated (Place 1974), evidence of the advantages of the uneven-aged model has more recently been advanced (Raymond 1988[6]; Haight 1987).

[6] Raymond, F.L. Forest Resources Group, OMNR (retired), 1988. Personal communication.

The two methods are contrasted as follows (modified from Godman [no date b]):

Even-aged Method	Uneven-aged Method
• Requires different basal area stocking for each thinning.	• Constant basal area target for each cycle.
• Removes many small trees at each thinning.	• Removes fewer but larger trees at each harvest.
• Early thinnings are economically marginal ("pulpwood").	• Thinnings are mainly sawlogs.
• Can market only part of periodic growth.	• Nearly all volume growth is marketable in regulated stand.
• Merchantable height often less than two log-lengths.	• Merchantable height often three log-lengths (due to fork correction).
• Possibility of sunscald and resulting butt rot.	• Sunscald rare.
• Favours shade-intolerant species regeneration, if site prepared.	• Favours shade-tolerant species.
• Excellent initial wildlife habitat.	• Low browse production.
• Ideal for production of fibre and of high-quality logs of more shade-intolerant species.	• Ideal for large, high-quality logs of shade-tolerant species.

Even-aged management is most appropriate in large areas of extensive forestry where forest productivity and resource funding are below the level required for uneven-aged management. On the other hand, uneven-aged management requires considerable expertise and funding but provides a continuous flow of high-value products from the better sites.

Each of these methods embraces a different array of silvicultural systems, which are briefly described as follows.

Even-aged Methods

- Clearcut system:
  The entire growth is harvested over a considerable area in one operation, with or without leaving seed-trees (OMNR 1986f). Reproduction is obtained artificially, or by natural seeding from adjacent stands, from trees cut in the clearing operation, or from individual or

groups of seed-trees left uncut on the area, or vegetatively from trees cut or damaged in the logging operation.

- Shelterwood system:
  Mature trees are harvested in a series of two or more cuts (preparatory, seed, removal, final) for the purpose of obtaining natural regeneration under shelter of the residual trees, whether by cutting uniformly over the entire stand area or in narrow strips (OMNR 1986f). These series of cuts are usually completed within a brief proportion of the rotation length.

UNEVEN-AGED METHODS

- Selection system:
  Mature and/or undesirable trees are removed individually or in small groups over the whole area, usually in the course of a cutting cycle. Regeneration is generally natural (OMNR 1986f). In this system, mature and immature timber (usually but not always including the largest or oldest trees) is removed at relatively short intervals, repeated "indefinitely," by means of which the continuous establishment of reproduction is encouraged to maintain an uneven-aged stand or an uneven-aged mosaic of even-aged groups of trees.

Some of these systems allow a variety of possible modifications (e.g., strip, patch, etc.) to suit specific conditions, but all share the same basic objectives.

The broad variation in site potential, species composition, stand quality, and the associated relatively high product values (with strict requirements for acceptability), combined with diverse management objectives, result in the use of a variety of silvicultural systems that must be employed to various degrees in order to adequately achieve these goals. Not all systems will be used to the same degree in all jurisdictions, depending on market availability, stand accessibility, site and stand quality, silvics of the species, environmental concerns, multiple-use requirements, and funding. However, a consistent rationale that employs the same factor evaluation should be used to ensure compatible policy application. It is recognized that the experience and local knowledge of the field forester will contribute greatly to the successful application of these methods. There is no doubt that the complexity of some of these intensive activities requires a correspondingly intensive level of training of technicians and forest workers and an adequate funding basis. This is especially important in terms of site evaluation and application of tree- marking technology. These factors are dealt with in detail in a companion report, *A Tree-Marking Guide for the Tolerant Hardwoods Working Group in Ontario* (Anderson and Rice, in press).

Recommendations for prescribing various silvicultural systems for the THWG vary greatly in the published literature (Petoskey 1982). Much of this variation is attributable to regional geographic differences, and evidence should be carefully weighed before application to Ontario. For example, clear cutting in strips and patches has been used successfully in the northeastern United States but has had poor results in the Lake States. This can be explained largely by differences in climate (the northeastern United States has greater precipitation, fewer droughts,

and is at lower latitude than the Lake States) and in soil depth, drainage and exposure. In addition, a wider range of species (e.g., white birch) resulting from treatment is acceptable in the northeastern United States (Godman, no date d).

Ontario is geographically situated between these two locations, but its growing conditions generally resemble the Lake States more than the northeastern United States. However, as was noted in Section 2.2, "Site," Ontario's hardwood forests occupy a great range of growing conditions and thus will not lend themselves totally to Lake States prescriptions. Therefore, a silvicultural treatment key is included (see Table 12) to provide guidance in prescription setting that is based largely on Ontario experience, augmented by published scientific literature.

Specific guidance for implementing marking procedures for both shelterwood and selection systems is outlined in *A Tree-Marking Guide for the Tolerant Hardwoods Working Group in Ontario* (Anderson and Rice, in press).

3.1.1 Clearcut System

Clear cutting removes the overstory in a single operation, laying bare the area treated, and leads to the establishment of an even-aged forest. Maximum cutover size is critical if natural regeneration is sought. Usually the patch should be limited in width to no more than five times the height of adjacent trees, unless seed-trees are purposefully left as a seed source.

Advantages include:

- efficient operations concentrated in space and time;
- no residual trees left that could deteriorate, although significant loss of advance growth may occur;
- only boundary marking required;
- simple regulation of cut by area;
- species diversity provides good wildlife habitat.

Disadvantages include:

- single opportunity for regeneration;
- competition often intense;
- entire stand exposed at one time;
- potential for erosion, runoff (on slopes), and aesthetic problems.

Modifications of the system include:

- Patch clearcut:
  Uniform clearcut with irregular boundary, conforming to land contours and often limited in size.

- Alternate strip:
  Two-stage clearcut in which cut strips (more than 40 m wide) alternate sequentially with uncut strips, whereby both are cut within the (ten-year) regeneration period.

- Progressive strip:
  Area is compartmentalized and adjacent strips (usually more than 40 m wide) are cut in sequential order within 20 years.

- Seed-tree:
  Up to 50 trees of seed-bearing age per hectare are retained to provide seed supply over the regeneration period.

An overall perspective on using clear cutting in even-aged forest practice is given by Nyland (1972).

Clear cutting to develop new even-aged stands from seed is the least suitable method for timber management of most THWG species. Application of any of the basic clearcut systems is extremely limited in the southern ranges of THWG species in Ontario. In some cases in the southern range, the low-quality overstory may be removed completely in a single "liberation" cut; however, in such cases, advance regeneration is always present and the system is better defined as a "one-cut shelterwood" (see Section 3.1.2, "Shelterwood System").

In the northern transitional forest (i.e., in the northern portion of Sections L.9 and L.10 [Rowe 1972], approaching the boundary of Site Regions 5E and 4E as shown in Figure 1), the clearcut system may be the only option available in cases where there is difficult access, and lack of funding and opportunity for investment in non-commercial harvest. In some cases where site and climatic conditions and stand quality potential are severely limited, management objectives may be effectively dedicated to fibre production using patch clearcuts, especially where hardwood pulp markets exist (such as the Algoma "Northshore" area).

In other cases, the common occurrence of poor-quality hard maple stands resulting partly from successive high-grading may suggest a commitment of the area to regeneration of species such as yellow birch that may have higher-quality potential on these sites. In these areas of limited access, where site protection and recreation potential are minimal but where advanced regeneration of intermediate shade-tolerant yellow birch is almost always lacking, the clearcut system with yellow birch seed-trees is recommended. In areas of better access, site preparation techniques may be used to enhance regeneration success. Roberge (1987) and Boivin (1985) have successfully used a modified strip clearcut to regenerate yellow birch in Quebec. However,

TABLE 12: Recommended Treatment Key for THWG Species Growing in Well-Stocked Stands on Suitable Sites

STAND DESCRIPTION	RECOMMENDED TREATMENTS
SEEDLING AND SAPLING STANDS (UP TO 9 CM DBH)	
1. Stands consisting of primarily hard maple and/or beech	
a) without overstory.....	1. Do nothing now; review when average dominant reaches pole size.
b) with overstory of less than 9 m^2 (24 cm DBH+) per ha basal area	
i) overstory with potential for future development.....	2. If seedlings, do nothing now; if saplings, apply light improvement cut to overstory.
ii) overstory with no potential for future development.....	3. Remove overstory if necessary to promote development of understory.
c) with overstory of 9 m^2 (24 cm DBH+) per ha or more basal area	
i) overstory with potential for future development.....	4. Apply improvement cut to overstory.
ii) overstory with no potential for future development.....	5. Reduce overstory to 9 m^2 (24 cm DBH+) per ha and further as necessary to promote development of understory.
2. Stands with a significant component of yellow birch, red oak, white ash, or black cherry	
a) without overstory.....	6. Do nothing now; review when average dominant reaches pole size.
b) with overstory of less than 9 m^2 (24 cm DBH+) per ha basal area	
i) overstory with potential for future development.....	7. Apply improvement cut to reduce crown cover to 40% of total.
ii) overstory with no potential for future development.....	8. If regeneration stocking is more than 50% and in sapling stage, remove complete overstory. If otherwise, reduce overstory to approximately 4.5 m^2 (24 cm DBH+) per ha.
c) with overstory of 9 m^2 (24 cm DBH+) per ha or more basal area	
i) overstory with potential for future development.....	9. Apply treatment to overstory (see "Sawlog Stands").
ii) overstory with no potential for future development.....	10. If regeneration stocking is more than 50% and in sapling stage, remove complete overstory. If otherwise, reduce overstory to approximately 4.5 m^2 (24 cm DBH+) per ha.
3. Stands with a significant hemlock component where it is desirable to retain the hemlock	
a) without overstory.....	11. Do nothing now; review when average dominant reaches pole size.
b) with overstory of less than 9 m^2 (24 cm DBH+) per ha basal area	
i) overstory with potential for future development	12. Do nothing now; review when average understory dominant reaches pole size.
ii) overstory with no potential for future development.....	13. Do nothing now; review when average understory dominant reaches pole size.
c) with overstory of 9 m^2 (24 cm DBH+) per ha or more basal area	
i) overstory with potential for future development	14. If understory is more than 16 m^2 (24 cm DBH+) per ha, reduce to 16 through improvement cutting. If between 9 and 16 m^2 (24 cm DBH+) per ha, apply light improvement cutting only where necessary.
ii) overstory with no potential for future development.....	15. If overstory is more than 16 m^2 (24 cm DBH+) per ha, reduce to 16. If 16 m^2 (24 cm DBH+) per ha or less, do nothing now.
4. Stands with undesirable regeneration.....	16. Regenerate to appropriate species using planting or seeding if necessary.

TABLE 12 (cont.)

STAND DESCRIPTION	RECOMMENDED TREATMENTS
POLE STANDS (9 TO 24 CM DBH)	
1. With no potential for future development.....	17. Regenerate to appropriate species.
2. With potential for future development	
a) without overstory.....	18. Apply crop-tree release and thinning.
b) with overstory	
i) overstory with potential for future development.....	19. Apply crop-tree release and thinning to polewood with improvement cutting in overstory.
ii) overstory with no potential for future development.....	20. Remove overstory. Apply crop-tree release and thinning to polewood.
SAWLOG STANDS (24 CM DBH AND UP)	
1. With no potential for future development	
a) no satisfactory regeneration	
i) overstory primarily hard maple.....	21. Regenerate using the uniform shelterwood system leaving a minimum of 11.5 m^2 (24 cm DBH+) per ha basal area.
ii) overstory with a significant component of beech where regeneration of beech is desired.....	22. Regenerate using the uniform shelterwood system leaving a minimum of 14 m^2 (24 cm DBH+) per ha basal area.
iii) overstory with a significant component of yellow birch, red oak, white ash, black cherry.....	23. Regenerate using the shelterwood system, leaving a minimum of 9 m^2 (24 cm DBH+) per ha basal area with sufficient openings to stimulate regeneration. Apply supplementary site preparation where necessary.
iv) overstory with a significant component of hemlock where regeneration of hemlock is desired.....	24. Regenerate using the uniform shelterwood system, leaving a minimum of 16 m^2 (24 cm DBH+) per ha basal area.
v) overstory species not desired.....	25. Regenerate to desired species using direct seeding or planting.
b) satisfactory regeneration present	
i) primarily hard maple and/or beech regeneration.....	26. Reduce the overstory to 9 m^2 (24 cm DBH+) per ha and further as necessary to promote development of understory.
ii) regeneration with a significant component of yellow birch, red oak, white ash, black cherry.....	27. If regeneration stocking is more than 50% and in sapling stage, remove complete overstory. If otherwise, reduce overstory to approximately 4.5 m^2 (24 cm DBH+) per ha.
iii) regeneration with a significant component of hemlock where the retention of hemlock is desired.....	28. If overstory is more than 16 m^2 (24 cm DBH+) per ha, reduce to 16 m^2. If 16 m^2 (24 cm DBH+) per ha or less, do nothing.
2. With potential for future development	
a) stand primarily hard maple or beech	
i) uneven-aged.....	29. Apply selection system using structure and stocking guidelines.
ii) even-aged.....	30. Apply even-aged stocking guidelines or adjust to uneven-aged structure.
b) stands primarily yellow birch, red oak, white ash, or black cherry.....	31. Apply appropriate even-aged stocking guidelines.
c) stands primarily hemlock.....	32. Apply selection system using hemlock stocking guidelines.

Metzger (1980) and Currell (1978) note that this method does not always work consistently well in regenerating shade-tolerant species like hard maple or hemlock.

When the desired species reproduces by sprouting (as do hard maple or red oak), or when direct seeding or planting is anticipated, seed source is not required and patch size is less critical but should conform to local land-use strategies.

3.1.2 Shelterwood System

The shelterwood system of reproduction involves gradual removal of the entire stand in a series of partial cuttings that extend over a fraction (20 per cent ±) of the rotation. Natural reproduction initiates under the protection (shelter) of the older stand and is released to form an even-aged stand when desirable to give the new crop use of the growing space (Smith 1962). Residual trees act as a seed source and will increase in size (and value) during the reproduction phase.

Advantages include:

- reproduction is more uniformly established than with clearcut or seed-tree method;
- rotation is usually shorter than with a clearcut;
- site is never fully exposed without tree cover;
- aesthetic quality is better than with a clearcut;
- financial maturity methods can be applied;
- weed competition is greatly reduced;
- it can be used to favour species that are moderately shade-tolerant.

Disadvantages include:

- requires more technical skill than for clearcut (but less than for selection);
- there is potential for logging damage to residuals and regeneration;
- costs more than clear cutting;
- residuals impede harvesting and site preparation;
- it is less advantageous for wildlife than clear cutting (but better than selection).

Cuttings may vary in configuration and number. Variations of the system include:

1. Uniform shelterwood:
   Canopy is (periodically) opened uniformly throughout the entire stand. This method is most applicable in instances where site or seedbed protection is essential, and aesthetics are a consideration. Usually, three cuttings are necessary to complete the process:

   (a) Preparatory cut: removes undesirable seed-source species and low-quality individuals and increases growing space for crown expansion of seed-trees.

   (b) Seed cut: further canopy reduction carried out preferably in, or just prior to, a seed year, which allows site preparation if necessary and creates the proper light regime for germination and establishment.

   (c) Removal cut: residual stand is totally removed later to release well-established regeneration, usually when seedlings are one metre or more in height.

2. Strip shelterwood:
   Canopy is opened in progressive stages in successive strips (less than 40 m wide), arranged sequentially in a compartmentized system. This method disperses the cut in space and time in the stand and offers efficiencies in production; the edge component is advantageous for wildlife. Strips may be reduced in width on south aspects. The last strip in the sequence may need to be regenerated artificially. This is often the method of choice for regenerating tolerant hardwoods on accessible, fresh, moderately deep loamy tills in the northern transitional forest.

3. Group shelterwood:
   Canopy is opened progressively in concentric bands from an original centre in the stand. This system is usually not recommended.

A recent overview of experience with the shelterwood method has been published by Hannah (1988a).

The shelterwood system is the most reliable method for successfully regenerating even-aged stands of the THWG, because these species usually must be established before the overstory is completely removed (Godman and Tubbs 1973). In this system, reproduction of less-tolerant species depends on canopy manipulation. Marking for shelterwood is based on per cent residual crown cover and *not* on basal area, because basal area is not a good indicator of canopy closure from species to species in stands with various diameters. For this purpose, crown area tables developed by Godman and Tubbs (1973) for the Lake States or by Leak and Tubbs (1983) for the northeastern United States may be used. Similarly, even-aged stocking guides may be used to indicate crown closure. It should be noted, however, that the "average" stocking line of Tubbs (1977b) in Figure 8a is the 100 per cent crown canopy level, while "maximum" is 110 per cent, and "minimum" is 80 per cent. On the other hand, the "A-level" of Leak et al. (1969) represents about 142 per cent crown closure and the "B-level" is nearly 90 per cent. A worksheet for shelterwood marking based on canopy closure is given by Godman (no date a).

Shelterwood systems are often used in stands of tolerant species such as hard maple that are not suitable for selection because of poor quality (defined as having less than 9 m^2/ha of basal area in trees 9 cm DBH and larger, or less than 7 m^2/ha in trees 24 cm DBH and larger of crop-quality [AGS]), excess age, or poor structure, or in stands of hemlock. This is the method of choice for reproducing most of the less-shade-tolerant THWG species such as red oak or yellow birch.

In instances where well-established (0.5 to 1.5 m in height) advance regeneration of hard maple, white ash, or red oak is present in a mature stand, the overstory may be removed in a *one-cut shelterwood* to release the regeneration and maintain a free-to-grow status. The preparatory and seeding cuts are not needed. In such cases, although the overstory is removed in a single cut, the regeneration has already been established naturally; therefore the procedure does not constitute a clearcut. This technique is sometimes also referred to as a "liberation" cut (see Section 3.1.1, "Clearcut System"). When applied to stands that contain some high-quality polewood, retention of part of this acceptable growing stock as residuals or "standards," to provide (with little investment) a later, intermediate harvest, may be justified as an option. However, such residuals often suffer, albeit temporarily, from excessive exposure; therefore, their crown condition must be closely monitored. Remedial improvement cutting may eventually be required to maintain residual quality and reduce unwanted competition to the regenerating stand.

If stocking of advance growth of these three species of hardwood is present but not well-established, a *two-cut shelterwood* is required. Here the preparatory cut is not needed. Thinning must take place *from below* and concentrate on removing the most-defective and least-vigorous trees, leaving better-quality trees for seed, site protection, and high-quality wood production. Crown canopy is reduced to 60 per cent, and winter harvesting is recommended to reduce skidding damage to the understory, although these species are capable of resprouting vigorously after damage that occurs in winter. The removal cut would be carried out when the regeneration is at least 1.2 m tall but before suppression effects are noted in leader growth (usually within five to ten years).

A *two-cut shelterwood* is also prescribed when regeneration of light-seeded species of less shade tolerance, such as yellow birch, is required. In this case, site preparation is necessary using pre-cut fall fire, herbicide, or summer logging and scarification to prepare the seedbed and reduce advance-growth competition. The cut should be from below and should leave 40 to 50 per cent crown cover (more on south aspects). A removal cut should be made when regeneration is well established (70 per cent or more stocking and at least 2.5 m tall; usually within ten years).

Where the heavy-seeded, shade-tolerant species (hard maple, white ash, and beech) exist as very sparse advance regeneration, or when it is desirable to regenerate light-seeded, shade-tolerant species like hemlock, a *three-cut shelterwood* is recommended. The preparatory cut is made from below to 80 per cent canopy closure. In the case of hemlock, cutting is concentrated on the hardwoods and retains a high stocking of hemlock. Logging is done in summer to improve the seedbed for hemlock. Planting or direct seeding can be carried out if necessary. A second cut in ten years reduces crown cover to 50 per cent (favouring removal of hardwoods) to partly release regeneration and maintain vigour. A final removal cut is made when regeneration reaches an acceptable height (1.5 m), which may require ten years or more. This technique may be used to

establish red oak regeneration using several light cuts (over an extended period of time) to build up the advance growth.

In hard maple stands, if residual "standards" are to be incorporated, they should be identified and reserved during the first marking. If regeneration is already established and in the sapling stage, a simultaneous improvement cut might be considered. Spacing of residuals should be regulated as follows:

- In overmature, defective stands with no potential, leave a minimum of 7 m^2/ha of basal area in trees of all sizes.

- In overmature stands with standards and with potential in smaller stems, leave 50 to 75 of the smaller, thriving trees per hectare at 12 to 15 m spacing.

Once polewood develops, it must be tended to maintain quality by initiating crop-tree selection and release.

3.1.3 Selection System

In practical terms, the selection system is a periodic partial cutting, controlled by basal area, using vigour and risk characteristics to determine individual tree selection. It is more than a reproduction system, since harvesting, regeneration, and tending are carried out simultaneously at each interval, producing an uneven-aged stand. The objective is to produce high-quality products through a representation of all diameter classes (ultimately all age classes) distributed throughout the stand.

Advantages include:

- growing space is occupied continuously, protecting the land and stabilizing the environment;
- there is permanent vertical closure of the stand (i.e., stand is more windfirm);
- visual impacts are minimized;
- there is a continuous flow of forest products of potential high quality, providing sustained yield;
- stand is less susceptible to violent fluctuations in biotic enemies;
- there is a permanent seed source;
- regeneration costs are low.

Disadvantages include:

- operations are relatively complex, requiring intensive training and supervision;

- harvesting is more expensive with greater difficulty (e.g., low harvest yield may result in elevated road costs);
- there is potential for residual stand damage at each cycle;
- many stands require time to optimize production;
- a strong market is often required for the disproportionate amount of low-quality material in early cuts; market conditions may preclude removal of all designated low-quality material in harvest cuts.

Variations of the system include:

- Uniform, or single-tree, selection:
  Individual trees are cut independently, the growing space being replaced by developing regeneration (of various sizes) that, when thinned over time, will result in replacement of approximately one tree at maturity. This method is exclusive to shade-tolerant species (i.e., hard maple, beech, hemlock, occasionally white ash). Edge effects are almost non-existent, minimizing availability of browse and species diversity for wildlife, although any cutting will tend to increase browse availability to some extent.

- Group selection:
  Trees are removed in small groups of two or more, usually occupying a fraction of a hectare, opening the canopy to a greater degree than single-tree selection. This technique is amenable to regenerating species of intermediate shade tolerance (i.e., yellow birch, red oak, white ash, occasionally black cherry), which additionally may require both cutting of smaller residuals to create a patch, and also site preparation. The objective is to maintain such species of intermediate shade tolerance in an uneven-aged stand by developing a staged mosaic of even-aged patches regenerated periodically in various cutting cycles. Edges are more clearly defined in this method and greater species diversity benefits wildlife.

It should be noted that normal application of the selection system usually results in a variable degree of canopy opening throughout the stand, some of which will emulate the effect of group selection for species that do not require site preparation to regenerate (e.g., hard maple, white ash).

The selection system should not be confused with the loosely used terms "selective cutting" or "diameter-limit cutting," which in most cases are used to mask a process of high-grading. Such techniques negatively affect the genetic base by leaving the poorer trees as seed sources.

Evaluations have been published for the selection system by Nyland (1987) and Marquis (1975), and for group selection by Leak and Filip (1977) and Roach (1974).

In Ontario, uneven-aged regulation, primarily implemented in Site Regions 5E, 6E, and 7E using the selection system in the THWG, is practised annually on approximately 30 000 hectares, of

which about 40 per cent is in Crown forest. The selection system is the system of choice for providing high-quality forest products with a minimum of aesthetic and environmental impacts, provided certain criteria are met. It can best be implemented on accessible, highly productive sites containing a major representation of shade-tolerant species (mainly hard maple), which have the capacity to respond to release at relatively advanced ages.

Preferable sites are fresh to moist (depending on species), developed on relatively deep, well-drained silty sands or sandy loams, often associated with morainic mid-slopes and drumlinoid landforms. For areas approaching the transitional forest in the northern portion of Site Region 5E, where the hardwood forest often has marginal quality potential, suitable sites[7] that can support adequate stands are noted in Figure 13.

In areas south of this, a basic level of management using selection system principles can be applied to "less-than-best" sites if reasonable structure and quality exist, although value growth, cutting cycle, and time-to-maturity will be affected adversely.

Qualifying stands should have a minimum of 9 m^2/ha of basal area in trees 9 cm DBH and larger (or 7 m^2/ha in trees 24 cm DBH and larger) of crop quality (AGS). Residual stocking in trees greater than 9 cm DBH must not be less than 11.5 m^2/ha of basal area, unless cuttings are designed to "condition" the forest structure *prior to* applying the selection system (see Table 12). Section 3.2, "Prescription Setting," discusses techniques for analyzing stand data to determine the appropriateness of choosing the selection system.

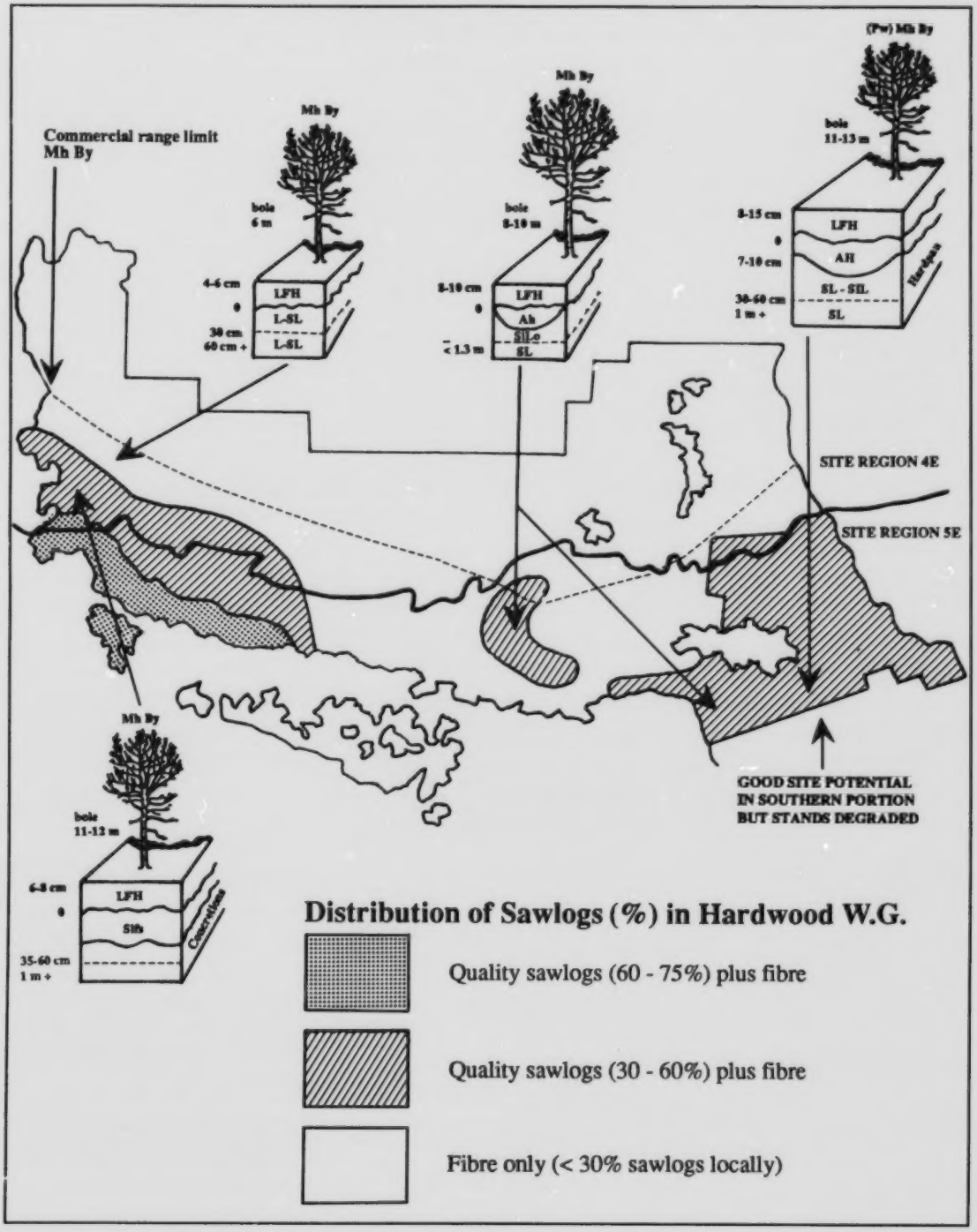
Decisions critical to successful application involve choice of cutting cycle, maximum residual diameter, stocking target, structural configuration (e.g., "Q-value"), and species composition requirement (i.e., inclusion of moderately shade-tolerant species). Details of stand parameter development are discussed in Section 2.5, "Stand Stocking and Structure," while quality criteria and marking guidelines are outlined in Section 2.4, "Quality Development in Trees." Qualifying stands will have the potential of developing recommended stocking and structure within 40 years (at most) while usually providing commercial harvests at each cycle.

Initial entry will often result in an *improvement cut*, whereby stocking targets are addressed while removing much of the poorer-quality material. Cull removal can be accomplished if markets exist for such material; otherwise such competition should be eliminated using other appropriate measures. Future cuts continue this process when necessary, and also serve as *conditioning cuts*, through which stand structure is improved and cutting cycles generally shortened to 10 to 15 years. During these operations, clumps of young growing stock may be retained to maintain clear-bole development, while older clumps are thinned.

The best-quality trees are retained as "residual capital" in order for them to grow and increase in value. All marked (yellow-painted) trees *must* be removed (especially wolf trees) and damage to residuals *must* be minimized (see Section 3.2.3, "Tree Marking") if these objectives are to be

[7] Kershaw, M. (formerly Regional Forest Ecologist, Northeastern Region), OMNR, Sudbury, 1987. Personal communication.

FIGURE 13: Distribution and characteristics of sites of varying potential for production of high-quality tolerant hardwoods near the northern transitional forest*



* Kershaw, M. (1987). Personal communication.

attained. Hard maple and beech respond well to single-tree selection. White ash, because of its regenerative ability and considerable shade tolerance when young, may regenerate under such minimal canopy disturbance, but effort must be expended to ensure that this species remains vigorous enough for it to maintain its stand position.

Group selection must be used to maintain (or introduce) species of intermediate shade tolerance in the uneven-aged forest. While stand marking is carried out under basal area control, crown closure is not linearly related to basal area and thus the degree of canopy opening becomes of prime concern within the group. Small patches of 0.2 ha are desirable (where possible) because they will usually regenerate, have acceptable aesthetics, and afford species diversity and ample edge effect for wildlife while preventing excessive invasion of competitive intolerants.

The size of the group or patch will control the successional species that will become established. Large openings (greater than 40 m wide) will encourage invasion by undesirable intolerant timber species, whereas smaller openings are operationally inefficient. In some instances, an array of patches in proximity may be site-prepared as a single entity. For yellow birch, patches of 0.1 to 0.2 ha are sufficient but must be accompanied by site preparation (fall burning, mechanical, or chemical). Under high deer populations, however, heavy browsing may eliminate the regener-ation in these small patches because of its limited distribution. Red oak can also be regenerated with modest site preparation using this technique, but the size of the groups must be somewhat larger. These species will not readily respond to release if suppressed to any degree and must be examined for thinning requirements at each cycle.

Stands developing from combined single-tree and group selection management will be uneven-aged and have a "reverse-J-shaped" frequency distribution, but will consist of islands of even-aged species of intermediate shade tolerance in a matrix of uniform selection forest.

3.2 Prescription Setting

The successful management of hardwood forests demands that any silvicultural intervention must be correctly carried out in two stages, namely:

- Prescription:
  Deciding what silvicultural treatment (if any) should be applied in a particular stand to achieve specific management objectives.

- Implementation:
  Preparing detailed instructions on how the prescribed treatment is to be carried out.

In intensive management, an adequate prescription will apply to a single stand or to a group of stands with similar attributes and requirements. Minimum information needed to define the treatment schedule includes the following:

- a clear statement of objectives (e.g., production of high-quality products, wildlife habitat improvement, fibre production)
- a knowledge of site quality and its place in the ecosystem
- a statement of desired species composition
- a quality cruise to define value and structure potential
- a knowledge of markets (both current and potential)
- an appreciation of access economics

Normally, intensive practices aimed at high-quality products will be prescribed only for accessible sites with high potential productivity. Sites of lower potential or poorer access may be managed by similar techniques but at a lower investment level and with a lower expectation of value growth.

3.2.1 Stand Analysis

When the objectives of management are diversified and include a range of potential silvicultural treatments, among which are those that lead to the development of uneven-aged forests through application of the selection system, a method of stand analysis must be used to identify those individual stands, usually composed of shade-tolerant species, that are amenable to, or have potential for, selection management.

In unmanaged forests, the variation in stocking from hectare to hectare is often considerable. From the vantage point of a tree-marker, perhaps only an area of 0.05 ha can be assessed from one place in the stand at one time, and this variation can be even greater. The dedication of the entire stand to selection would be based on its overall condition, recognizing that the prescription would allow local discretion in marking provided that overall stand targets and objectives are met.

Poor stand development and performance may reflect unsuitable site conditions, which will impose limitations on potential value growth and justifiable investment level. Many stands, however, are of variable quality simply because of historical events (such as high-grading, natural catastrophe, or even lack of disturbance), rather than limitations of site or biological potential. The manager must consider whether such stands have the qualities required to support the relatively intensive investments characteristic of the selection system. Procedures for evaluating the quality, stocking, and structure of hardwood stands are provided in *A Tree-Marking Guide for the Tolerant Hardwoods Working Group in Ontario* (Anderson and Rice, in press).

3.2.2 Prescription Development

Since hardwood stands are so variable, and since prescriptions will vary with the unique combinations of factors described previously, this section can deal only with general guidelines. An overall decision pathway is provided in Figure 14, which outlines some of the fundamental management routes available in treating THWG stands, the details of which will be described in Sections 3.4, "Forest Renewal," and 3.5, "Stand Maintenance."

Of more practical use, a treatment key is given in Table 12, which provides a sequential, discriminant pathway leading to an initial approximation of an appropriate stand prescription. The branch-point decisions in the key that involve stand quality potential use the results of the stand analysis procedures referred to in Section 3.2.1, "Stand Analysis."

Other sources of prescription keys are found in the published literature for THWG species such as Leak et al. (1987, 1969) for northern hardwoods in the northeastern United States; Marquis et al. (1984) for Allegheny hardwoods; Trimble et al. (1974) for Appalachian forest stands; Roach and Gingrich (1968) for upland central hardwoods; Sander (1977) for oaks in the north central United States; Arend and Scholz (1969) for oaks in the Lake States; Tubbs (1977b) for northern hardwoods in the Lake States; and Brand (1981) for oak and northern hardwoods in the Lake States.

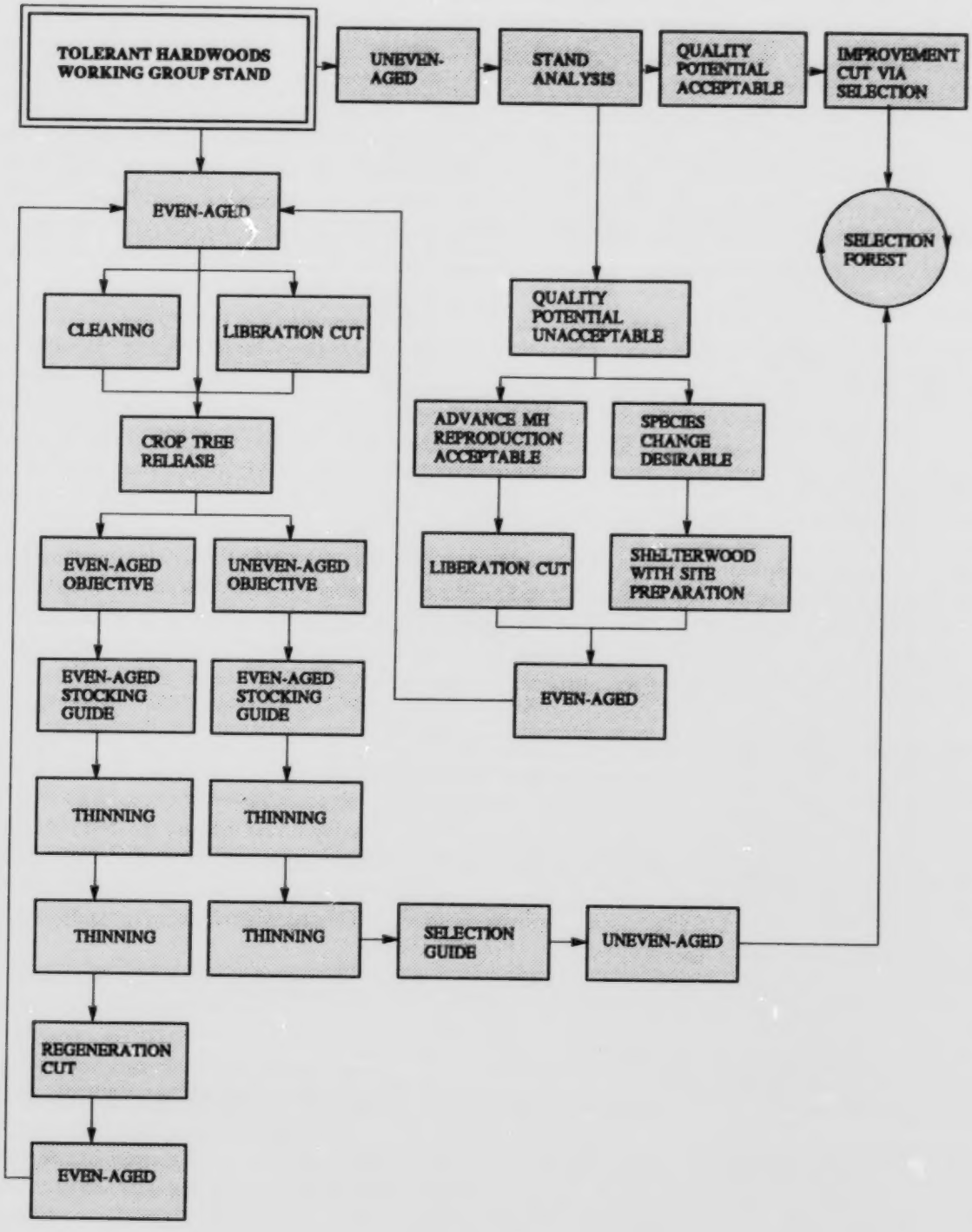
In Ontario, treatment keys have been written by Irwin (1988) for ANSI (areas of natural and scientific interest) applications in southern Ontario hardwoods (OMNR 1987b). A tolerant hardwood key given in *Management of Tolerant Hardwoods in Algonquin Provincial Park* (OMNR 1983) has been adapted for general use in the Algonquin Region. The key presented here (in Table 12) is a modification of the two last-mentioned items, adapted to reflect the appropriate THWG species.

This key applies only to the production forest and to sites considered adequate for quality growth of THWG species. The range of sites found in each of the three major ecological sectors is outlined in Section 2.2, "Site." Integrated resource management may require alterations of prescribed silvicultural treatments in some cases to meet specific and/or local needs. In following the modified route, however, it should be realized that timber production targets may not be fully achieved. All references to silvicultural systems must be considered with respect to established guidelines, ground rules, and policies.

3.2.3 Tree Marking

Tree marking is the mechanism for implementing the regulation of forest management prescriptions that involve partial cutting, as with the single-tree selection system, in which trees are marked for removal (usually with yellow paint), or with the uniform shelterwood system, crop-tree release, and thinning procedures, in which residual trees are marked (usually with blue paint). It is important that the prescription indicate the management objectives in terms of the

FIGURE 14: Decision pathways for prescribing silvicultural treatments in stands of the THWG



silvicultural system to be employed, the quality of products considered, the implementation of measures concerned with non-timber values, and the long-term horizon for the designated area.

Marking is usually a compromise between maximizing present harvest in terms of volume and value, and optimizing timber production in terms of future growth and quality while providing suitable conditions for the regeneration and maintenance of other forest values. The nature of this compromise often causes variation in application from place to place (McLean 1976).

The effort of stand diagnosis and prescription setting is wasted if marking objectives cannot be effectively carried out in the field. Sometimes a structural goal cannot be met because of local stand conditions. Good silviculture is more important than strict adherence to a structural guide; however, no marking should be undertaken without a structural guide regardless of the partial-cutting system prescribed (Leak and Filip 1975).

Quality of marking must not be sacrificed to reduce costs. Poor-quality marking wastes money and can reduce the future development of forest values. Considering the silvicultural importance of the procedure and the potential value of products, marking costs seem to be a modest and justifiable expenditure (Trimble and Wendel 1963).

Trees selected for removal in partial cuts are marked with yellow paint, usually on two sides, and at DBH and stump levels. This should be done in a manner that will aid recognition and prevent accidental removal. Trees marked for reserve (such as in shelterwood or improvement cuttings or in crop-tree release operations) are marked with blue paint, which should be of a quality that will not cause cambial damage (Stone and Frederick 1979).

Details on the implementation of tree-marking procedures for single-tree and group selection and for uniform shelterwood systems are outlined in *A Tree-Marking Guide for the Tolerant Hardwoods Working Group in Ontario* (Anderson and Rice, in press).

3.3 Harvesting Considerations

Logging operations are a critical element in forest management. Poorly planned and executed logging may provide immediate profit but can also negate cultural efforts and future productivity in the THWG. On the other hand, well-planned, careful operations can have minimal visual impact, maintain environmental and stand values, and still generate income. In an increasingly mechanized enterprise, the forest harvest, especially in uneven-aged management, requires complete preplanning and layout before the operation begins. Overviews of the effects of logging on northern hardwoods and of effective skid-trail construction are given by Nyland et al. (1976) and by Fisher and Taber (1975) respectively. Section 3.5.2, "Protection," outlines principles of felling and skidding techniques designed to minimize damage to residual trees. Techniques by which timber removal can be accomplished with the least visual impact are outlined in *Timber Management Guidelines for the Protection of Tourism Values* (OMNR 1987i).

Quality control of lumber starts in the woods, not at the mill (Petro 1965). Techniques to maximize the value recovery in felling and log-making have been presented by OMNR (1986e), FPAPA (1984, 1979), and Petro (1971). The logging system used almost exclusively in commercial THWG operations employs a traditional cut-and-skid technique, usually a feller with a chainsaw combined with an articulated skidder with operator. Products are skidded either as log-lengths (shortwood) or tree-length to roadside or a central processing area. Log-length operations are efficient, moving only high-value tree sections, and tend to cause minimal damage to residuals if done properly. They do not lend themselves to integrated (multi-product) operations. Tree-length operations, which transport the entire merchantable bole (without limbs and top) as an integral piece, increase productivity and the chance for multiple-product recovery, but tend to cause greater damage to advance regeneration and residual trees because of reduced skidding flexibility. A third system, full-tree logging, in which the entire tree is transported from the stump, is rarely used and potentially can cause significantly greater damage and slash build-up on the landing sites. The choice of system will depend on the availability of markets for the products encountered. The trend toward tree-length logging, while increasing the utilization of low-end products, may be silviculturally regressive since the additional value may be offset by the increased damage to higher-value residual crop trees.

Logging equipment should be selected to match the size and weight of the timber being harvested (McCraw 1967). Conventional skidding or forwarding equipment is very expensive to operate, while small machinery or draught animals have limited efficiency over long skidding distances. It is important to organize the logistics and configuration of the harvest very efficiently. Articulated rubber-tired wheeled skidders should be restricted to the 80-to-120 horsepower range in selection and shelterwood cuts in mature stands in an effort to reduce skidding damage. Using winching techniques in skidding practice will further benefit quality maintenance (see Section 3.5.2, "Protection"). Using skidders on fine-textured moist soils can result in soil compaction, rutting, and root damage (see Section 2.9, "Environmental Considerations"). In these instances, where possible, operations should be delayed until freeze-up. Harvesting when the ground is snow-covered will also tend to reduce skidding damage to advance regeneration. As an alternative, crawler-type vehicles (equipped with tracks) may be used on certain sites with less environmental impact because the weight distribution causes lower load-bearing pressures on the tracks.

Small bulldozers and farm tractors may be used in some woodlots, especially when retrofitted with equipment for winching and piling. Skidding damage to residuals is similar to that caused by wheeled skidders but soil disturbance is usually less. Skidding costs are high with bulldozers because of slow travel time and high maintenance costs. Techniques for minimizing logging damage are described in Section 3.5.2, "Protection."

Logging damage is determined more by the manner in which a machine (or animal) is used than by the type of equipment. Generally, the larger the machine, the greater the potential for environmental impact. In practical terms, choice of equipment is a trade-off between daily productivity and environmental impact. Skidding equipment that can operate efficiently and economically over long distances can reduce this type of damage simply by reducing the extent

of the road network required (Place 1974). *Environmental Guidelines for the Construction of Access Roads* (OMNR 1988) outlines the necessary procedures for mitigating environmental concerns associated with this aspect of harvesting.

Safety in the workplace has become a high priority in harvesting operations. Workers must remove all potential hazards such as chicots before proceeding to work on an area. This is a requirement under the Occupational Health and Safety Act and Regulations for Industrial Establishments (Province of Ontario 1985), and has implications for the maintenance of cull or dying trees as den trees or for use by cavity-nesting birds in habitat maintenance programs. It may also restrict the use of stand improvement techniques such as girdling that can create potential safety hazards for forest workers.

3.4 Forest Renewal

Forest renewal is a sequence of silvicultural operations for the successful establishment and development of regeneration. In some instances involving less-shade-tolerant species forming even-aged stands, a "new" forest is produced to replace the old mature forest after harvest at rotation. In other cases, involving shade-tolerant species growing in uneven-aged stands, the process is ongoing over time, producing the so-called "continuing" forest (Wray et al. 1985). In all cases, management prescriptions must be tailored to the requirements of the species of interest in order to attain successful forest renewal. This involves creation of favourable micro-environments that fulfill the species' biological requirements for overhead cover, root and aerial growing space, and seedbed characteristics, especially for light, temperature, and moisture. It should be noted that the micro-environment for a species may change across the Site Regions of Ontario, as indicated in Table 2.

In the THWG, the new crop is usually established using a silvicultural system (clearcut, shelterwood, or selection) in which natural regeneration is obtained in the form of seedlings or sprouts. In cases of seed-crop failure or out-of-step seed years, artificial means such as direct seeding or planting are used. For some species, site (seedbed) preparation is required in combination with the above options. In addition, proper site selection to match the species' developmental requirements is essential, if not for establishment, then for optimum growth and performance at later stages. Some silvical characteristics of individual species that influence prescription setting for regeneration purposes are:

- seed-crop frequency and viability,
- seed weight and dispersal features,
- seedbed requirements for moisture and nutrients,
- light budget for germination and establishment,
- shade tolerance,

- juvenile vigour,
- sprouting ability.

Against these biological requirements, the forest manager must evaluate local options such as the range of silvicultural methods that are practical and the availability and accessibility of adequate sites.

Some THWG species, such as hard maple, beech, and white ash, in some circumstances, can be managed under all three silvicultural systems. These species exist as advance growth, have medium-to-heavy seed that germinates vigorously, establish without seedbed preparation, are relatively shade-tolerant, and sprout easily.

Other species, such as yellow birch or hemlock, have very light seed, produce fragile germinants, and require specific combinations of site, overhead shade, and seedbed preparation. Oak, on the other hand, can establish on the unprepared forest floor but suffers greatly from seed predation. However, it sprouts very well and can be effectively promoted by using prescribed fire (sequentially if necessary) to eventually attain free-to-grow status. Black cherry seed, conversely, may remain dormant and buried in the organic layer for several years and can reproduce "spontaneously" after stand disturbance.

A conceptual decision model outlining the usual options considered for THWG forest renewal is presented in Figure 15.

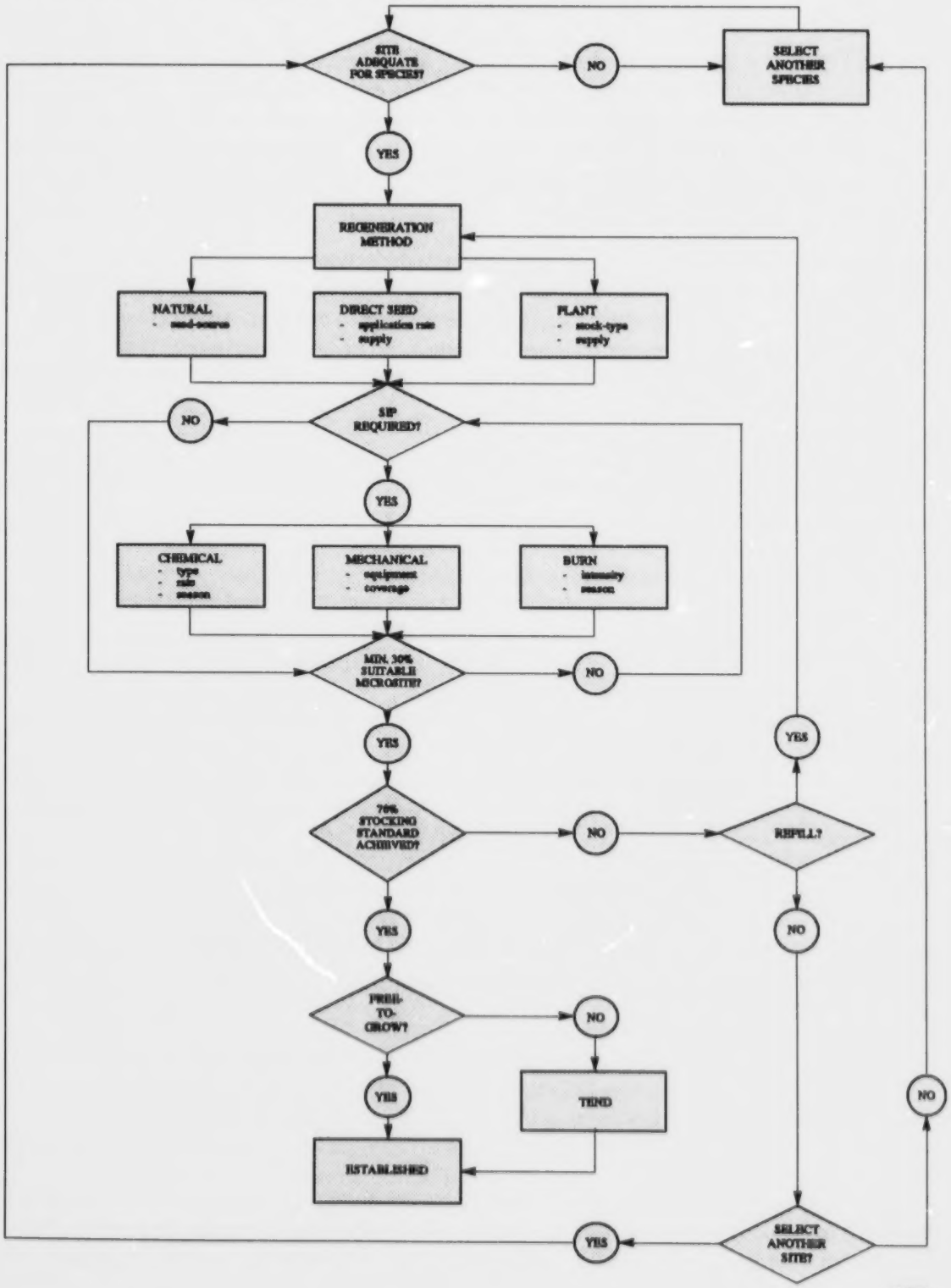
3.4.1 Site Preparation

Site (seedbed) preparation is not required for medium- and heavy-seeded species of high or intermediate shade tolerance (i.e., hard maple, beech, white ash, red oak, and black cherry). In fact, it is usually detrimental because many of these species regenerate from advance growth present prior to cutting. Also, oak and cherry germinate better when covered by litter or buried in organic material. Site preparation is not a concern in uneven-aged management of most shade-tolerant species.

The small- or light-seeded species such as yellow birch and hemlock require specific seedbed conditions to establish successfully. Both prefer a lightly disturbed forest floor in which litter is removed and the organic layer and upper mineral soil horizons are mixed in a crude cultivation. The shade tolerant hemlock will survive some immediate competition (and in fact prefers partial shade) but will grow slowly. Yellow birch is less shade tolerant; it requires some overhead protection but will not survive intense competition from raspberry or maple advance growth.

Sites are prepared for development of regeneration (where necessary) by (i) eliminating immediate severe living competition, (ii) creating a suitable seedbed in terms of moisture, texture, and continuity characteristics, (iii) redistributing slash (if required), and (iv) reducing compaction or improving drainage of surface soil. In some cases, a specific shade or protection requirement

FIGURE 15: A decision model for securing regeneration in the THWG



may be involved. In many cases in the THWG, site preparation usually refers to seedbed conditioning and microsite development (steps [i] and [ii] above).

In partial-cutting practices, especially, slash is not a problem where markets encourage close utilization, and typical sites rarely need surface structuring except in planting procedures. Heavy equipment is usually not required and extensive areas of treatment are not common. In the northern transitional forest, where strip cutting or seed-tree methods are used in single-species even-aged regeneration prescriptions, more specialized equipment may be employed for greater efficiency.

Methods of site preparation consist of three basic types: (i) mechanical, (ii) prescribed fire, and (iii) chemical. Each has its own characteristic effects, and the three are not mutually interchangeable although they often have synergistic effects when combined (see Table 13). Useful overviews of site preparation methods are given by Sutton (1985) and Stewart (1978).

3.4.1.1 Mechanical

Physical disturbance of litter, slash, and vegetation on the forest floor (scarification) accompanies logging operations during skidding of logs and maneuvering of equipment on-site. This method usually results in crude cultivation of the forest floor, removal of leaf litter and compaction reduction. It results in relatively limited coverage (10-15 per cent) unless logs are deliberately channelled to separate skid trails; however, this practice could lead to increased logging damage to residuals. Scarification as a planned activity, as distinct from disturbance by harvesting, employs bulldozers equipped with toothed blades or root/rock rakes to avoid scraping too deeply which would result in displacement or removal of nutrients in the organic soil layers. The skill of the operator is more important than the type of machine. Drag-type scarifiers such as 10-kg-link anchor chains equipped with gouging pins are effective in breaking up litter, ripping out established competition, and mixing the humus and mineral soil to create a suitable seedbed type, which is so critical to yellow birch and hemlock (Anderson and McCormack 1967).

Wheeled skidders may also be used in place of tracked vehicles but must be used cautiously in wet weather to reduce rutting and erosion. Angle dozer-blades, root-rakes, and V-blades may be appropriate in strip cuts, where extensive scarification is prescribed in post-harvest application. These methods can handle extensive slash accumulations and can root out undesired advance growth (Horton 1964).

Pre-harvest scarification is most applicable where a seedbed is required under a partial canopy, such as with shelterwood systems. Damaged trees can subsequently be removed during harvest. While the system can treat entire areas, some prepared sites may be lost under subsequent logging slash.

Most mechanical methods are relatively expensive depending on site accessibility, machine type, and degree of treatment required. A review of current uses and trends of mechanized site preparation techniques is given in Smith (1987). An overview of silvicultural equipment

TABLE 13: Comparison of Effects of Site Preparation Methods (from Stewart [1978])

SIP Method	Removes Debris	Reduces Competition	Prepares Seedbed	Reduces Compaction	Creates Microsite
Mechanical	++	+	+	++	++
Prescribed burn	+	++	+	—	—
Chemical	—	++	—	—	—
Combination	+	+	+	+	+

++ Very Effective + Effective — Not Effective

appropriate for the THWG is given in Smith (1981) and techniques appropriate for assessing their efficiency are described by Sutherland (1986).

3.4.1.2 Prescribed Fire

In the THWG, most prescribed burns are surface leaf-fires, consuming fine fuels (twigs) and leaf litter only to the depth of the fermenting layer. They do not involve logging slash, and cause only minor and ephemeral ecological change (Anderson 1982). Exceptions to this rule may be in cases of stand conversion to conifer, where "brown-and-burn" techniques may be employed. The role of fire in forest site preparation in Ontario is described by Dixon (1982). Procedures for planning prescribed burns are described in *Prescribed Burn Planning Manual for Crown Lands in Ontario* (OMNR 1987c), OMNR Aviation and Fire Centre Procedure No. PR AF .03 .23 .02 (1980), *Prescribed Burning*, and *Forest Manager's Photo Guide to Prescribed Burn Planning* (Wearn et al. 1982).

Pre-harvest fall burning will prepare an adequate seedbed, eliminate seedling and small-sapling advance growth, and destroy most seed resting on the forest floor. An exception is cherry seed, which may escape injury by being buried in the moist organic layers. Damage to residual growing stock is minor, but in most cases such stems would be removed in the seeding cut. When the objective is to kill larger stems (for example, coppice clumps), a spring fire is recommended. However, species such as oak often resprout after top-kill.

Customized burning (to favour yellow birch, for example) is possible. Pre-harvest fall fires are run after leaf-fall (usually in mid-October), when maple and beech seed has fallen, but birch seed has not. Birch seed falls throughout the winter, is stratified in the melting snow, and ultimately lands on the burned seedbed. If logging is carried out subsequent to burning, incidental scarification will occur to further enhance at least part of the seedbed.

Burning may not be economically practical or efficient in group selection, where the patches are relatively small (0.2-0.4 ha), although it is certainly feasible and can be successfully practised if conditions warrant the time and effort on a local scale. This would be done only to maintain even-aged patches within an uneven-aged stand. However, it can be usefully applied more easily under shelterwood methods where the treated areas are more extensive and contiguous.

Fires can also be designed for heat-effect (killing power) by prescribing according to burning index. Burn intensity will affect the depth of the burn and the size of residual trees killed or damaged.

Burning is relatively cost-efficient (per net hectare treated) but is subject to the uncertainties of weather and is less selective in terms of avoiding areas of concern (i.e., it is an "all-or-nothing" option). Considerable skill is required to execute prescribed burns, although application techniques have been well researched for use in yellow birch regeneration (Anderson 1982; Burton et al. 1969; Sykes 1964; Sinclair 1962; Holowacz 1960; Burton and Sloane 1958).

3.4.1.3 Chemical

Herbicides may be used to kill unwanted vegetation in order to reduce competition and prevent potential resprouting. It is efficient in terms of time and often relatively inexpensive. However, it leaves the forest floor physically undisturbed and therefore does little to create seedbeds suitable for light-seeded hardwoods. To avoid significant environmental impact, application must be planned and executed by licensed individuals with knowledge and training in the use of chemicals registered for forestry use (OMAF 1988; Province of Ontario 1980), in accordance with OMNR Forest Resources Branch Procedure No FR 04 05 10 (1984), *Controls on the Operational and Experimental Use of Pesticides in Forest Management.*

Effectiveness depends on choice of chemical, target-species' susceptibility, method of application, season of year, and immediate weather conditions. The use of chemicals alone as a site preparation method is limited to cases where weed vegetation is very susceptible, slash density is low, and litter is not a barrier for the species to be regenerated. Chemicals may be foliar- or soil-active, contact or systemic, selective or non-selective. Depending on the objective and target-species size, herbicides can be applied by foliar or basal spray, injection, or granular distribution, all in ground application.

The use of herbicides as a site preparation tool in the THWG is limited to only a few specific circumstances. This tool has potential for use in managing yellow birch and red oak by controlling low competition prior to seedling establishment under the shelterwood system. Chemical site preparation can be used alone as an alternative to mechanical site preparation or to prescribed fire with heavy-seeded species like red oak. It can also be used in sequential treatment with mechanical site preparation (in place of prescribed fire) for light-seeded species like yellow birch. The principal advantage of herbicide use is the prevention of resprouting from the root or root collar, a condition that occurs frequently and vigorously following light surface fire or mechanical site preparation.

In shelterwood situations, ground-based application is a requirement. The need for large volumes (up to 1100 litres per hectare) of carrier for most ground-based applications has made this treatment prohibitively expensive in the past. Recent innovations in ground-based delivery allow a great reduction in carrier volume (and in the amount of herbicide itself) while delivering effective treatment.

As this more cost-effective delivery becomes more available, the use of herbicides for site preparation can be expected to increase, especially if the use of other forms such as fire is constrained (for instance, by weather or fire-danger conditions).

3.4.2 Regeneration

All seven of the major THWG species can be regenerated naturally using appropriate silvicultural treatments, some more easily than others. Most can be established artificially by direct seeding or planting, although this is usually the choice only where seed source is lacking or conditions are adverse to those necessary for natural regeneration to occur. However, success will be fully achieved only when the proper micro site is created by the chosen procedure for the target species (Blum 1975). While working groups are addressed according to the dominant species, treatment combinations or sequential modifications may be required to maintain certain species in mixture.

General overviews of natural regeneration methods for THWG species are given by Crow and Metzger (1987), Bjorkbom and Walters (1986), Nyland and Marquis (1978), Tubbs et al. (1983), and Arend and Scholz (1969).

3.4.2.1 Natural Regeneration

Hard Maple

A shade-tolerant, heavy-seeded species, hard maple can reproduce and thrive without seedbed preparation under partial-cutting systems such as single-tree selection or group selection and readily regenerates as an even-aged stand in shelterwood cuttings (Tubbs 1977a). It will dominate in clearcuts if well-established (about one metre tall) advance growth is present before cutting. It does not regenerate well from seed, or compete effectively in severe openings associated with block or strip clearcuts except where the area is rapidly invaded by short-lived raspberry or brush species, which may tend to inhibit the growth of intolerant tree species. Hard maple may regenerate under dense raspberry cover but may require ten years to become fully stocked and free-to-grow. In some cases, strong stump sprouting from smaller stems may dominate parts of clearcuts.

Recommended regeneration procedures are determined largely by site and overstory quality. If overstory is uneven-aged and of good quality with developing structure growing on fresh silty

sands or sandy loams, single-tree selection is the system of choice. Stocking levels are maintained to promote quality growth and yield in the overstory (14-16 m^2/ha, 24 cm DBH and larger), with stand structure subsequently adjusted to ensure recruitment of the developing regeneration into growing stock at each cutting cycle (15-20 years). Height growth of regeneration will vary with overstory stocking level but should be about 30 cm per year. If the current stand is overmature or of poor quality, even-aged procedures such as liberation cuttings can be used if advance growth is well advanced (one metre or more tall); a two-cut uniform shelterwood can be employed if new regeneration is required. In the latter case, a cutting from below to retain a crown density or canopy closure of 60 per cent should be employed. No site preparation is needed if the target species is hard maple. The overstory is removed in winter logging when regeneration exceeds one metre in height (before height increment begins to diminish) and should represent about 12 400 stems per hectare (Tubbs 1977a).

Dense second-growth hard maple pole stands seldom contain much advance growth because of lack of seed source. Thinning before 40 to 60 years of age will not stimulate much reproduction; however, tending through a rotation will usually result in a maple understory at maturity.

If the growth and quality of the stand is inferior because of site limitations (e.g., dry moisture regime; shallow soil; imperfectly drained soil; or heavy-textured soil), conversion to other species such as pine or spruce (or in some cases aspen) is recommended. The appropriate silvicultural guide should be consulted for regeneration prescriptions.

Beech

A heavy-seeded, shade-tolerant species similar to hard maple, beech will reproduce on unprepared seedbeds in partial shade associated with single-tree selection. Higher overstory residual densities (greater than 16 m^2/ha) may favour the relative density of beech regeneration, and its lack of browse potential aids its survival. Seed supply may be limited by bears foraging for mast. Beech generally does not undergo significant regeneration in stands in which crowns are opened significantly, such as with shelterwood or clearcuts. In stands with overmature beech, thickets of root suckers may exist, most of which seem to have low potential to develop into larger timber unless specifically tended. The generally low timber quality of beech usually results in this species being marked for removal in improvement cuts. Retention of mast trees in uneven-aged practice will usually ensure a beech understory component while also providing food for wildlife.

White Ash

A moderately heavy-seeded species that exhibits considerable shade tolerance at young ages, white ash can be regenerated without site preparation (especially in Site Regions 6E and 7E) using several methods. Uneven-aged stands containing white ash seed-trees often show good regeneration (Trimble 1965b), which must be favoured by release during partial cuts under the single-tree selection system prescribed for hard maple. Group selection employing small gaps (0.04 ha) will favour white ash establishment and survival (Leak and Wilson 1958). Wind-dispersed seed will allow establishment in shelterwood and clearcut areas but seed viability is

often low, with seeds exhibiting delayed germination. Thus the species seldom dominates reproduction in clearcuts. Stump sprouting is well developed and sprout stems often grow faster in height than seedlings do.

Yellow Birch

A light-seeded species of intermediate shade tolerance, yellow birch requires partial overhead shade on a very-fresh-to-moist sandy-loam site (MR 3-5), preferably with a telluric water table and a seedbed comprising a mixture of humus and mineral soil (Burton et al. 1969). Maple and beech litter is a barrier to germinant rooting and must be removed in site preparation either by mechanical means (summer logging and deliberate pre-cut scarification to achieve 50 per cent coverage) or pre-harvest fall prescribed burning (after leaf-fall, before snowfall). Maple, beech, or ironwood advance growth must also be eliminated from the vicinity of the seedbed, using herbicide if necessary.

Seed is wind-dispersed for long distances over early winter. From 5 to 12 seed-trees per hectare are required, depending on size. Birch can be maintained as an even-aged mosaic in an uneven-aged selection forest of hard maple by employing group selection (Trimble and Hart 1961). Canopy openings should be no greater than 0.20 ha to provide partial shade and exclude competitive intolerant weed species, but height growth will be maintained only if canopy openings are adjusted periodically. Yellow birch is a favourite deer browse and may be seriously inhibited by heavy feeding pressure.

Yellow birch can be regenerated well using a two-cut shelterwood system (Godman and Erdmann, no date) implemented during a good seed year (about every three years). Overstory canopy density or crown closure should be reduced to 50 to 60 per cent on scarified sites or 60 to 70 per cent on burned sites (Tubbs 1977b). Early mortality is high and successful stocking requires a minimum of 25 000 seedlings per hectare after one year. Under proper light conditions, first-year height growth should exceed 15 cm. Where overstory density is maintained at 70 per cent crown closure, some additional thinning may be required if regeneration does not maintain a height increment of at least 45 cm per year. The overstory should be removed in winter when seedlings are 1.8 to 2.4 m tall. In such conditions, yellow birch will dominate hard maple of the same age, but the advantage disappears if canopy closure significantly increases. Yellow birch will regenerate without seedbed preparation only in the friable litter under hemlock, but growth is slow and seedlings seldom survive.

In stands of the northern transitional portions of Site Region 5E, where the site and quality of hard maple suggests conversion to the better-adapted yellow birch, the regeneration technique will depend on accessibility. Where relatively intensive management is proposed on accessible sites, a three-cut strip shelterwood is proposed, with strips about one tree-height in width. Cutting would discriminate against hard maple while yellow birch seed-trees would be retained in each cut, scheduled six to seven years apart. In areas not readily accessible, a clearcut with seed-trees (evenly distributed at 50 to 60 m intervals throughout the area) would be employed as a basic management strategy, but with reduced expectations for stocking and future yield.

Hemlock

A light-seeded, shade-tolerant conifer, hemlock regenerates best in cool, moist microsites influenced by partial shade (Erdmann and Godman 1987). It usually regenerates spontaneously but irregularly in dense hemlock stands and grows very slowly. The species regenerates poorly on the thick humus mat on the forest floor of pure mature stands, and hardwood litter is a definite barrier to establishment. For successful reproduction, either seedbed preparation involving mechanical scarification mixing organic and humus layers or prescribed fall fire, is recommended (Godman, no date e). This species is sensitive to sudden exposure and is most successfully regenerated by a three-cut shelterwood when advance growth is sparse, especially in mature stands with a hardwood component.

An initial cut from below is made in a seed year to reduce the canopy density to 80 per cent (about 23 m^2/ha of basal area in trees 24 cm DBH and larger). Cutting is often done in summer to achieve site preparation. Supplemental scarification may be difficult due to high residual stand density. Hardwoods should be discriminated against in cutting. A second winter cut is made to a canopy density of 50 per cent to partially release the seedlings when they average about 30 cm in height. A final cut is made when the regeneration reaches one metre in height (Tubbs 1977b).

In stands where some hemlock advance growth exists, a two-cut shelterwood can be employed, eliminating the first stage of the three-cut system. Group selection using relatively small canopy gaps (0.04 ha or less) has also been suggested for hemlock.

Black Cherry

A heavy-seeded, relatively shade-intolerant species, black cherry will reproduce on fresh loams on unprepared seedbeds but requires overhead light to survive and grow. Since seed is often dispersed by birds into areas with no cherry in the overstory, and because seed can remain buried in the organic layers in a dormant condition, stand disturbance may give rise to black cherry stocking where none is expected (Auclair and Cottam 1971). The buried seed is not usually consumed in light prescribed surface fires and may in fact be stimulated to germinate by such activities.

Black cherry is most successfully reproduced, if a seed source is available, using group selection (0.04 ha) (Trimble and Hart 1961) or uniform or strip shelterwood (Marquis 1979) in which one-third of the basal area is harvested to control the invasion of weeds. Once established (that is, greater than one metre in height), the overstory should be removed (Smith 1983), since height growth increases exponentially up to full light (Gottschalk 1985). This species usually outgrows hardwood associates, with the exception of aspen. It is often selectively and intensively browsed by deer (Hough 1959).

Red Oak

A heavy-seeded species of intermediate shade tolerance, red oak is perhaps the most difficult THWG species to regenerate consistently (Johnson 1979). It can reproduce without seedbed

preparation but suffers from severe predation of acorns from wildlife and insects. Regeneration is often easier on drier sites (Hilt 1985b; Trimble 1973) but quality development and yield are best on fresh-to-moderately moist (MR 2-4) sites, especially those best described as protected "cove" sites.

One key to successful establishment is to delay overstory removal until advance growth is dominant and well established (i.e., basal caliper of 1.3 cm or 1.2 m in height). This can be achieved using shelterwood cuttings (Hill and Dickman 1988; Clark and Watt 1971) leaving 60 per cent crown cover or using group selection with patches 0.2 ha in size. Site preparation may increase the potential for establishment. It may be advisable to kill advance growth of tolerant species such as hard maple or beech with herbicide to ensure site capture by the oak (Johnson and Jacobs 1981). Another alternative is to run a prescribed fire through the regenerated area to eliminate top growth, after which the oak should resprout and capture the site (Johnson 1974). Selective release using herbicides may be necessary to ensure adequate growth. Such cuttings will work best if carried out in a bumper oak seed-crop year, which should provide adequate seed even in the presence of rodent predation. In some cases, the process may be repeated sequentially to build up sprout vigour and stocking (2500 stems per hectare) of oak before complete release. Cuttings should be frequent enough to maintain good crown form (apical dominance) in seedlings (Bey 1964). Flat-topped seedlings will show delayed height-growth response to release (Carvell 1967).

Because the use of clear-cutting techniques to regenerate oak has provided extremely variable and conflicting results, such methods are best avoided at the present state of knowledge, except as a complete release of established advance growth (Johnson 1976).

3.4.2.2 Direct Seeding

The use of direct seeding in the various THWG species is a supplementary silvicultural technique usually employed in cases of seed-crop failure, inadequate catch of natural regeneration, or lack of available planting stock. The technique has been used in Canada since 1900 but between 1900 and 1972, direct seeding of THWG species amounted to only 0.7 per cent of the total area seeded (Waldron 1973). Techniques include broadcast application or seed-spotting in scalped seedbeds. In some cases, density control is a problem if uneven dispersal occurs. Much of the mechanization recently developed is more applicable to boreal species than to THWG species (Brown 1973).

Guidelines for forecasting and collecting tree seed are given in *Guidelines for Tree Seed Crop Forecasting and Collecting* (OMNR 1986b). Most species require stratification to effect rapid germination; this normally occurs overwinter. Some species, like hard maple, germinate at cold temperatures (1° C to 2° C)(MacArthur and Fraser 1963), often beneath a snow cover; they are often therefore seeded in nurseries in the autumn (Carl and Yawney 1977), although there is usually little need to artificially seed maple in forest conditions. Yellow birch, often a companion to hard maple, germinates at higher temperatures and usually later in the spring, a fact that offers

a competitive disadvantage to birch in some cases (Tubbs 1965). Direct seeding of yellow birch has been successfully carried out at both the experimental level (Roberge 1977; Hatcher 1966) and the operational level (Ashenden 1957). Tests of direct seeding of black cherry have had negative results unless the seed is buried (Huntzinger 1964).

The species that benefits most from direct seeding is red oak, because of its general difficulty in regeneration. Tree-collected acorns are more viable than those collected on the ground (Teclaw and Isebrands 1986), but germinative potential can be increased by eliminating cull acorns using salt flotation (230 to 285 g NaCl/l, depending on moisture content) as described by Johnson (1983). Pericarp removal will modify dormancy and greatly increase the germination of freshly collected acorns (Hopper et al. 1985). Godman and Mattson (1980) recommend stratifying acorns overwinter and pregerminating them by slightly raising temperatures for 12 to 14 days. These should then be seeded in the spring immediately after snowmelt to take advantage of favourable cool temperatures and to minimize predation. Sowing acorns at a five-centimetre depth may favour establishment (Johnson and Krinard 1985).

The specific recommendations of Godman and Mattson (no date) for direct seeding of hard maple, white ash, yellow birch, hemlock, and red oak are summarized in Table 14.

3.4.2.3 Planting

All THWG species can be planted successfully under properly prepared conditions. However, such measures are undertaken only when alternatives are limited—for example, when natural regeneration or direct seeding attempts have failed; to introduce genetically improved materials or special species mixtures; to improve wildlife habitat; and to achieve the afforestation of open fields or idle land.

Forest Plantings

Regeneration by planting is usually carried out in conditions where the survival potential of seed-based systems is low (e.g., in older cutovers), as dedicated underplanting using species that are otherwise difficult to regenerate (e.g., red oak in shelterwood), or in attempts to quickly improve wildlife habitat (e.g., hemlock planting).

Godman (no date c) has stressed the importance of matching site to species, top pruning, using large stock, planting immediately after site preparation, creating proper overhead canopy conditions, and planting groups of single species, or mixing species that have similar growth rates and habits.

Planting such species as yellow birch, hard maple, and white ash is usually confined to conditions where natural regeneration is difficult (Francis and Bivens 1985; Gottschalk and Marquis 1982; Hannah and Turner 1981).

Perhaps the most important application of forest planting is with red oak, a species noted for its reproductive inconsistency. Considerable success has been achieved in the Missouri Ozarks

TABLE 14: Recommendations for Direct Seeding of Species in the THWG (from Godman and Mattson [no date])

Species	Site Preparation	Sowing Rate (per hectare)
Hard maple	none	3.4 - 10.0 kg
White ash	none	2.2 - 7.8 kg
Yellow birch	mixed humus/mineral	0.13 - 0.37 kg
Hemlock	mixed humus/mineral	0.37 - 0.74 kg
Red oak	scarify or burn	1235 - 3700 acorns

using a four-step prescription (Johnson et al. 1986; Johnson 1984b). They recommend underplanting 1+1 red oak stock of at least 10 mm in basal diameter, that is clipped back to a 15 cm top length before shipping. Stock should be planted in a shelterwood thinned to 60 per cent stocking (the "B" line of Gingrich [1967]), and the overstory should be removed after three growing seasons. Competition is partly controlled by applying appropriate herbicides to cut stubs of unwanted woody understory vegetation and stumps before planting, and again at the time of overstory removal. To prevent herbicide damage if foliar application (e.g., glyphosate) is used, oak reproduction can be cut before the herbicide is applied; the oaks will resprout the following year. Using this prescription, one-third to one-half of planted trees can be expected (in Missouri) to be successfully established (free-to-grow) two years after the shelterwood is removed. Table 15 indicates the probable number of planted trees needed to ensure a target density after shelterwood removal, in relation to initial basal-stem diameter. Johnson (1984b) also found that among trees planted directly into clearcuts, success probabilities were greater for container-grown stock than for any class of bare-root stock for a given basal diameter.

Similar studies are being conducted in the Algonquin Region by Stroempl (1986) and Gordon (1986) using prescriptions similar to that of Johnson (1984b) but including the use of spring prescribed fire and a variety of reproduction techniques such as acorns germinated in tubes and spot-sown acorns.

Hemlock has been established by planting primarily for aesthetics, or more practically for improvement of wildlife habitat (Jordon and Sharp 1967).

Open-field Planting

Open-field planting is primarily carried out on private land in southern Ontario. However, opportunities do arise related to amenity planting or afforestation of open land that reverts to the Crown or otherwise is required for forest production. Good overviews of techniques and prescriptions for this condition are given by Von Althen (no date) and OMNR (1977). Selecting a

TABLE 15: The Number of Planted Red Oak Needed to Establish a Specified Density (in Missouri) by the End of the Treatment Period (modified from Johnson et al. [1986])

Initial Basal Diameter (mm)	Probability of Success	Number to Plant for One Success	Number/ha to Plant to Get 1200/ha Established
1+0 and 2+0 Seedlings			
4	0.04	20.00	24000
8	0.18	5.56	6672
12	0.33	3.03	3636
16	0.44	2.27	2724
1+1 Transplants			
4	0.06	16.66	20040
8	0.29	3.45	4080
12	0.53	1.89	2280
16	0.63	1.59	1920

- Seedings clipped back to 15 cm above base before planting
- Assumes shelter removed between third and fourth growing seasons
- An established tree has annual net height growth of 40 cm for 2 years after shelterwood removed

proper planting site, site preparation, post-planting weed control, planting-stock quality, planting method, and rodent control are identified as major factors affecting plantation establishment (Von Althen 1979a, 1979b). Godman (no date c) notes that good weed control will avoid severe rodent damage and seedling mortality and Russell (1971) recommends deep planting for oak to increase the probability of establishment.

Prescriptions for planting and tending red oak, sugar maple, white ash, and black cherry have been outlined by Von Althen and Webb (1980) and Von Althen (1979a, 1979b, 1974a).

3.4.2.4 Conversion to/from the THWG

Some areas support working groups (other than the THWG) that may not be efficiently suited to the site. For example, white pine may occupy deep rich sites as a result of fire or other disturbance. While they may have performed very well in the past, an encroaching, aggressive hardwood understory may impose great difficulty in efforts to regenerate the pine. Or, a good

site may be occupied by poplar, again because of disturbance, which may or may not have THWG species in its understory. In both cases, it may be wise to develop the new crop as a THWG, either by releasing adequately stocked established hardwood regeneration using liberation cuttings, or by further enrichment of regeneration through seeding before release. Techniques used to establish red oak in conifer plantations by underplanting have been demonstrated by Stroempl (1987a, 1987b). Subsequent management would be in accordance with concepts and procedures outlined in this guide.

In the converse situation, hard maple or red oak may be aggressive on dry, nutrient-poor sites, where they will grow relatively slowly and have low-quality potential. One option might be to manage the hardwoods extensively for fibre products only. However, it may be more appropriate to convert the site to a more productive working group such as white pine, a species more adapted to these conditions. In such cases, the hardwood might be used as a "nurse crop"; doing so would involve carrying out a shelterwood cut to control light intensity, implementing site preparation to control the hardwood understory competition, and establishing the pine by direct seeding or planting. Specific procedures for these conversions are contained in the appropriate silvicultural guide for whichever working group is chosen.

3.4.2.5 Stocking-Level Targets

A mature, fully stocked stand of tolerant hardwoods can disperse 20 to 25 million seeds per hectare in a good seed year (Benzie 1959b). As many as 2.5 million seedlings per hectare may persist for the first year. Survival rates for yellow birch seedlings (as well as others in the THWG) may be only 40 per cent by year five and 10 per cent by year ten in stands managed by recommended prescriptions, such as group selection for yellow birch. Because of sheer seedfall density, after nine years as many as 198 000 seedlings per hectare can survive, ranging in size from 15 cm tall to 1.27 cm DBH (Tubbs 1977a). The dynamic nature of the population over time prompted McEwen et al. (1958) to recommend that "stocked" milacre sample plots (equivalent to 4.05 m^2) be required to have ten established seedlings at the end of one growing season and that satisfactory stocking be defined to mean that 80 per cent of quadrats are classified as stocked. Tubbs (1977a) recommends a minimum of 12 355 well-spaced seedlings, or 2471 saplings (5-10 cm DBH), per hectare.

To be considered successful, regeneration on an area must be established to meet minimum stocking standards and height requirements and be free of competition that impedes growth by the end of the standard regeneration period. Forest stands that reach this requirement are termed "free-to-grow" and are returned to the forest land base in the youngest age class. Minimum seedling density of acceptable species is recommended to be 12 355 stems per hectare.

Minimum standards have been set locally by the various OMNR Regions. The selection system is not covered by the benchmark standards. Stands managed under this system are considered to be in a state of continuous growth and therefore deemed to be free-to-grow at all times. Areas regenerated by shelterwood or clearcut should be assessed for free-to-grow status, preferably after the first, second, and fifth growing season.

For the uniform shelterwood system, for example, the Algonquin and Eastern Regions have proposed the standards shown in Table 16. In the Northeastern Region, however, standards have been derived in a different manner, which reflects a difference in management strategy related to accessibility, stand quality, markets, and site potential.

In the presence of mixed species or sprout stems, and for areas comprising both natural and artificial (planted) regeneration, the free-to-grow criteria are difficult to apply. Smith (1983) found that hard maple mixed with red oak and black cherry developed very poorly despite the fact that it was maintained for 12 years in a free-to-grow condition.

A useful technique for determining future stocking of oaks with reasonable accuracy has been developed by Johnson and Rogers (1985) for estimating the contribution of planted stock, and by Sander et al. (1984) for evaluating advance reproduction (seedlings and sprouts) for future development. Both use research data to develop success probabilities for each species, which estimate the numbers of trees needed to produce a single established tree at a future date. An example of this approach is shown in Table 15.

Predicting later growth, needed for projecting development to allow entry into the stocking table of Gingrich (1967) at about age 20 years, is facilitated by using tree-area equations to estimate required growing space. This technique also allows the determination of the number of stump-sprouts needed to compensate for deficiencies in natural (advance) regeneration in oak stands treated under various silvicultural systems.

3.5 Stand Maintenance

Once a stand has been regenerated, it must be maintained and protected from establishment to maturity by a series of intermediate treatments. These treatments ensure survival, regulate the growth of the developing stand, and may provide early financial returns. Not all treatments may be necessary to maintain quality and vigour depending on species, site, markets, and the silvicultural system being used. In fact, in the selection system, harvesting, regenerating, and tending (often combined with sanitation cuttings) are carried out simultaneously rather than in a staged sequence. Protection measures include recognizing and controlling important insect and disease pests (see Section 2.3, "Silvics") of each species, and also using planning techniques designed to avoid excessive logging damage. A conceptual model of the decision process in evaluating THWG maintenance requirements is given in Figure 16.

3.5.1 Tending

Tending procedures are designed to ensure continued productivity of forest stands by: (i) increasing the volume growth and the value growth of selected crop trees, (ii) shortening veneer- and sawlog-tree rotations, (iii) improving tree quality and species composition, and (iv) increasing total yield of products by salvaging high-risk trees and smaller individuals that would

TABLE 16: Free-to-grow Standards for Uniform Shelterwood Regeneration in Algonquin and Eastern Regions

Forest Unit	Site Class	Free-to-Grow Minimum Stocking	Stocking Objective	Minimum Total Height (m)	Regeneration Period (yrs)
Mh/Oh MIX	X,1	> = 80% Mh, Or, By, Bd, Aw, Cb	> = 90% Mh, Or, By, Bd, Aw, Cb	1.0	5
Mh/Oh MIX	2,3	> = 70% Mh, Or, By, Bd, Aw, Cb	> = 80% Mh, Or, By, Bd, Aw, Cb	1.0	5

otherwise die. Treatment response in diameter and height growth will vary with species, size, crown position, crown vigour (crown size, live crown ratio, foliage density), and growing space made available (Erdmann 1987). Table 17 summarizes the various types of tending treatments that may be considered in THWG management.

Treatments aimed at regulating species composition and improving the quality of young stands are called *release* cuttings. These are divided into three types:

- *cleanings*, which are made in a sapling stand to free the best trees from undesirable individuals of the same age that overtop them;
- *weedings*, which remove all plants competing with crop species regardless of their competitive status;
- *liberation cuttings*, which free young sapling stands from competition involving older, overtopping individuals.

It should be noted that because both cleaning and weeding procedures not only are prohibitively expensive but also may be detrimental to the stand if not properly applied, they should be considered only for small areas of unique value (e.g., ANSI locations, gene pools, etc.). A conservative but effective alternative is to encourage seedling and sapling stands to grow undisturbed until crowns have closed and merchantable lengths of clear bole are established appropriate for the species and the site class.

Treatments aimed at regulating species composition and improving the quality of older stands (i.e., those past the sapling stage) are called *improvement* cuttings. They remove trees of undesirable species, form, or condition (such as overmature or leaning individuals) from the main canopy.

Treatments aimed at controlling stand growth are called *thinnings*. These regulate the distribution of growing space for the advantage of the existing crop. Thinnings may be made from above (crown thinnings) or from below. *Crop-tree thinning* considers individual trees as

FIGURE 16: A decision model to assess maintenance requirements of developing stands of the THWG

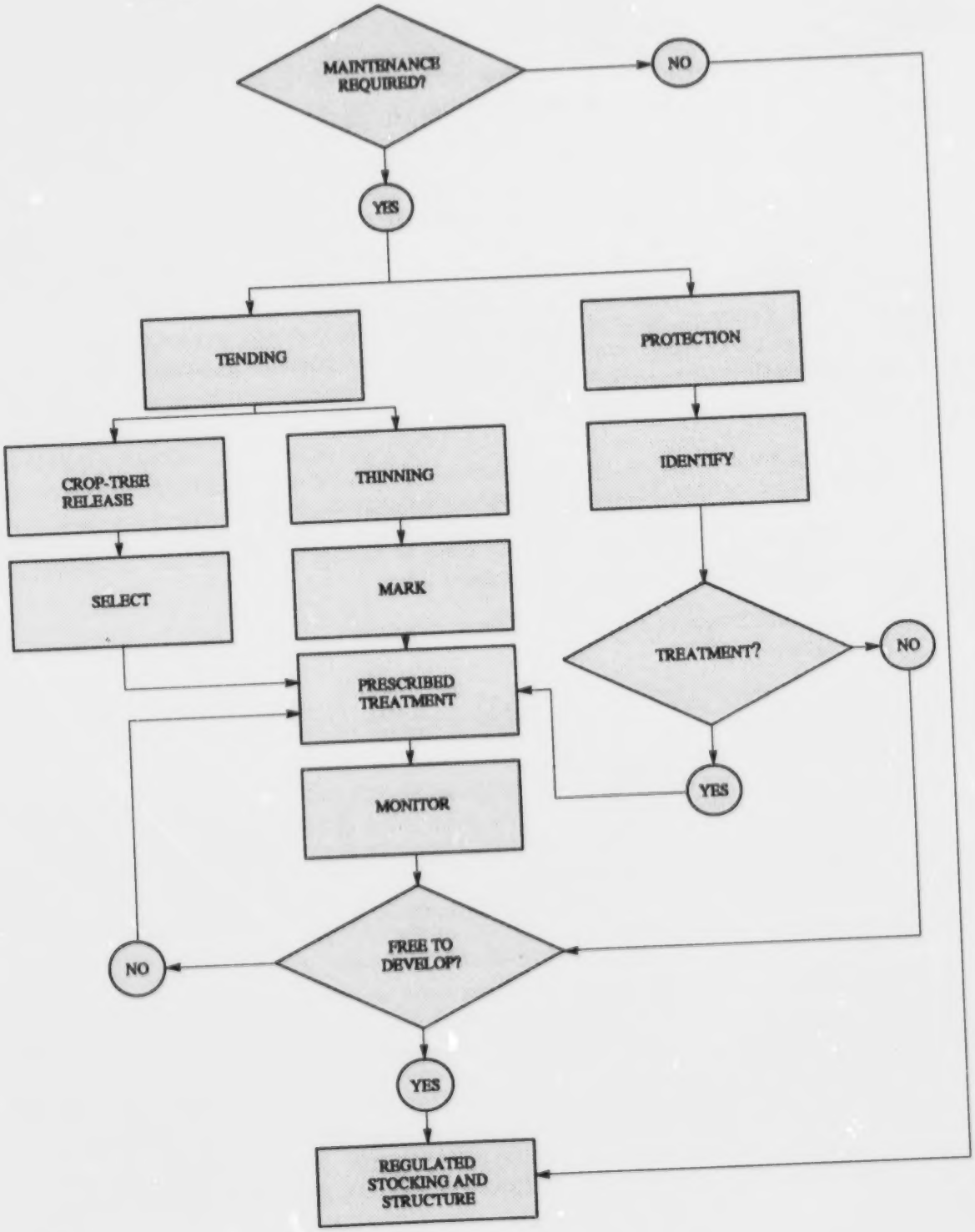


TABLE 17: Summary of Intermediate Treatments Carried Out in Stand Maintenance (from Beattie et al. [1983])

Treatment	Stage	Purpose	Trees Removed	Trees Retained
Release Cutting				
Cleaning*	Sapling	Regulate species composition and tree quality.	Unwanted species. Trees of poor form.	Crop-tree species of good form.
Weeding*	Sapling	Regulate species composition.	Unwanted species.	Crop-tree species.
Liberation	Seedling/ sapling	Release young stand.	Older, larger overtopping trees.	Seedling/sapling. Regeneration.
Improvement Cutting				
	Pole and larger	Improve species composition. Improve quality.	Unwanted species. Poorly formed, overmature trees.	Well formed. Desirable species with potential.
Thinning				
Low thinning	Pole and larger	Salvage mortality. Reduce root competition.	Lower crown class.	Middle/upper crown class.
Crown thinning	Pole and larger	Increase crop-tree growth. Salvage mortality.	Poorly spaced trees in upper crown class.	Well-spaced, well-formed trees in upper crown class.
Pruning				
	Pole/ Max DBH 20 cm	Improve lumber quality.		

* Usually not cost-effective under operational conditions and may be detrimental to the stand if improperly applied

candidates for a final crop and releases their crowns to allow development of high-value products. Thinnings for high-value products in the THWG should be done only on this basis.

Stand maintenance may also include procedures to increase bole quality through eliminating branches by *pruning*. In THWG species this is often accomplished by *natural* or *self-pruning*, which results from maintaining proper stand density. Some situations justify *artificial pruning* to accelerate value increment.

Using herbicides for tending purposes in the THWG is uncommon. Most herbicide use involves converting stands from hardwoods to conifer, where the hardwoods have established on sites that are relatively unproductive (for hardwoods). Such sites have normally been site-prepared and planted after cutting under the uniform shelterwood or clearcut system.

Hardwood species are unique in that any cutting in the stand will affect bole quality through changes in stand composition, stem form, clear-bole length, merchantable height, insect/disease problems, climatic effects, and tree growth. Godman and Erdmann (1983) have summarized some of the factors affecting tree quality:

- Stem forking:
  Caused by loss of terminal bud resulting from bud miner, frost, or leader breakage. This problem is common in maple, ash, and birch; recovery is related to stand density and is delayed or prevented by excessive crown exposure.

- Epicormic branching:
  Caused by flushing of dormant buds on the bole following exposure after thinning. It is not serious on trees with large, healthy crowns.

- Limb-free length:
  Affected by rate of branch mortality and shedding due to side-shade. It is related to stand density. Acutely angled branches are often associated with natural-pruning defects (included bark, stain, etc.).

- Stem canker:
  Nectria on yellow birch and *Eutypella* on maple jeopardize the survival of affected stems.

- Climatic influences:
  Sunscald injury to polewood is promoted by excessive thinning on exposed sites with southerly aspects.

Identifying potential crop-tree quality is an important first step in all tending procedures for high-value products. Crop trees of any species should have the following characteristics:

- desirable species (By, Or, Cb, Aw, Mh);

- dominant or codominant healthy crowns only (also intermediate crowns of shade-tolerant species);
- good form—butt log of grade-1 potential;
- bole straight and clear for 50 per cent of height, ideally developing 7.5 to 10 m without branches or V-shaped forks;
- free of major surface defects or internal decay;
- free of black knot (Cb), *Nectria* (By), or *Eutypella* and maple borer (Mh).

Specific guidelines on these factors are noted in Section 2.4, "Quality Development in Trees."

Subsequent procedures differ depending on the management strategy and silvicultural system used. Godman (1986) suggests a few general rules for improving stand growth and quality in stands in the Lake States (which may be useful guides for southerly portions of the THWG range):

- Consistently maintain proper stand density. When in doubt, leave a slightly higher stocking.
- Select to leave the best individual, uniformly spaced crop trees, within stocking and structure guidelines, on the basis of crown size and stem form.
- Never cut below 11.5 m^2/ha of basal area (in trees larger than 11.7 cm DBH), even if undesirable trees have to be retained.
- Recognize stand variation during the marking process.

Algonquin Region standards recommend minimum stocking levels of 11.5 m^2/ha (9 cm DBH and larger) of basal area in selection and shelterwood stands, and 13.75 m^2/ha in even-aged polewood THWG stands.

3.5.1.1 Uneven-aged Stands

For uneven-aged tolerant hardwood stands managed under the selection system, regeneration, harvesting, and tending are combined into one operation in periodic cuttings. Tending of intermediate age classes occurs in the process of structuring a stand (see Section 2.5, "Stand Stocking and Structure") to achieve a balance in the growing space allocated to different diameter classes (Nyland and Marquis 1978). In high-graded or unmanaged stands, this is accomplished by improvement cuttings, the major goal of which is to concentrate or transfer growth to the best-quality trees in the stand by removing overmature, cull, or wolf trees. In defective stands, where no market exists for low-quality material, overstory stems may have to be eliminated by girdling or poisoning with herbicide. This would result in a more gradual release to the advance

reproduction. As a result of this treatment, cull and defect characteristic of overmature stands become minimal after the third cyclic cut, provided that logging damage is controlled.

Many cull trees die after logging. In the northeastern United States, 39 per cent of the residual culls over 18 cm DBH died within five years and 46 per cent were dead within ten years due to shock from sudden exposure, and windthrow. Mortality was even higher for smaller cull trees. It is recommended that large (marked) culls be eliminated before, during, or immediately after logging. Smaller culls may be left for five years since 40 per cent may die within this period, and cull developing from serious logging damage could be assessed and remedied if necessary at the end of the five years (Trimble and Smith 1963).

The selection method of cutting offers an excellent opportunity for an appreciable reduction in the proportion of cull in hardwood stands. After three selection cuts, Trimble (1965a) found that sawlog defects were reduced progressively, amounting to 20 per cent, 8 per cent, and 5 per cent of gross log scale. By the third cutting, the proportions of sound and defective material had stabilized and the process of reducing cull was finished. Volumes of cull can be maintained at 1 per cent or less of gross (board-foot) volume, and stands may be expected to produce sawlogs with average scaling deductions of 4 to 5 per cent.

Similarly, Cooley (1964), working in Michigan, found that much cull in poor-quality stands is caused by overmaturity or mismanagement and that cull development does not progress as rapidly as harvest under proper application of the selection system. In sawtimber trees existing at the beginning of the study, the percentage of unmerchantable volume decreased from 40 per cent to 28 per cent to 4 per cent after one, two, and three harvests, respectively.

Trimble (1963) noted that the development of new cull trees is remarkably slow in managed stands from which culls had been removed. New culls developed mainly as a result of logging damage, but cull-tree elimination should be only a minor and periodic operation after one thorough initial treatment has been made.

Bole quality of smaller trees, especially of hard maple, tends to improve with increased stand density (Godman and Books 1971) and increasing site quality. Cutting in sapling classes is unnecessary. It is important to move polewood stems into the main canopy to maintain a relatively dominant crown position capable of continued satisfactory growth while at the same time maintaining stocking in polewood clumps to ensure continued self-pruning to the lower 7.5 to 10 m of bole. Pole-sized trees benefit most from cuttings that leave no more than 14 to 16 m^2 of basal area per hectare. The duration of response depends on the degree of cutting and the cycle length must vary with cut intensity and rate of regrowth by the residual stand. Unlike less-tolerant species, hard maple is "elastic" and will tend to respond to release even at an advanced age and often after significant suppression. In hard maple stands, structure is maintained by recruitment into saplings and poles from advance reproduction commonly available on the forest floor. The height-growth response of small seedlings to varying degrees of release indicates that there is little response from light cutting. Over a typical 20-year cutting cycle, there is a linear response in average height increment as residual overstory basal area (9 cm DBH and larger) is reduced from 22 m^2/ha down to 10 m^2/ha. Further reductions in basal area, however, do not produce

greater height-growth response—and, in fact, may decrease it. Cutting to recommended stocking levels in the Algonquin Region on appropriate sites should result in average height increments of approximately 25 cm per year in hard maple seedlings/saplings over a 20-year cutting cycle. It should be noted that cutting below stocking targets (see Section 2.5, "Stand Stocking and Structure") to accelerate structural recruitment will cause some loss of residual volume growth (OMNR 1983).

In instances where stand analysis (see Section 3.2.1, "Stand Analysis") indicates that quality potential is poor and the overstory should be eliminated, a liberation cut (see Section 3.1.2, "Shelterwood System") should be carried out to fully release advance reproduction of hard maple. In this case, average height increments could be expected to be 50 cm per year over the 20-year cycle, and even more in the most vigorous stems. Such development would put the stand into polewood in the 21 to 40 year age class. This will produce an essentially even-aged stand, which should be tended accordingly (see Section 3.5.1.2, "Tending Even-aged Stands").

Cultural work in the understory of uneven-aged forests is generally less beneficial to the residual stand than cultural work in the overstory. However, when group selection (or patch cutting) is practised (for example, to encourage yellow birch to regenerate within the uneven-aged forest), there are better possibilities for such procedures in the essentially even-aged young growth (Leak and Filip 1975). Tending at each cutting cycle entry is required to eliminate overstory crown encroachment as required to maintain a free-to-grow condition.

3.5.1.2 Even-aged Stands

Even-aged stands may arise through deliberate activities such as shelterwood or liberation cuttings, or due to exploitive situations involving clear cutting (such as for chemical wood or fuelwood). Where few veteran overstory residuals remain, the resultant condition is often referred to as "second growth." Stands often contain a mixture of trees of desirable and undesirable species, quality, and origin. Good overviews of the results of various tending treatments applied to even-aged hard maple, yellow birch, red oak, white ash, and black cherry are provided by Erdmann (1987, 1983) and Lamson and Smith (1987). Some general recommendations for tending are presented in Table 18.

Even-aged stands may be cultured to maturity over time using a series of cuttings designed to favour desirable stems and maintain them in a dominant or "free-to-grow" condition.

Cleaning

This treatment is *not* usually recommended in sapling stands because it is expensive and is a long-term investment. Such precommercial release in any case is attractive only in stands managed intensively for high-value products (Higgs 1981), where in some studies return on investment has been found to be as high as 6 to 10 per cent (McCauley and Marquis 1972). Methods for economic evaluation of management decisions have been demonstrated by LeDoux (1986); Hynard (1984); Gunter (1983); Leak (1980); and Olson et al. (1978). Cleaning is not recom-

TABLE 18: Recommended Even-Aged Tending Techniques for Valuable Species in the THWG

Species	Stage of Development		
	Sapling	Pole	Sawlog
Yellow birch	Cleaning not necessary if species captures site. Potential crop trees must maintain live crown ratio > 25%.	Delay crop-tree release until stand closes and bole clear length is 8 m. Crown release about 250 trees per hectare.	Maintain dominant crown position of crop trees by removing two important competitors. Maintain even-aged stocking guide levels.
Hard maple	Cleaning not recommended.	Delay crop-tree release until stand closes and bole clear length is 8 m. Crown release about 250 trees per hectare.	Maintain even-aged stocking guide levels or convert to uneven-aged structure and stocking guide levels.
Black cherry	Clean only to maintain survival. Delay at least until age 12 for growth response.	Release crop trees before age 40 or before crown ratio falls below 40%.	Maintain crown position, size, and vigour of crop trees to avoid loss. Maintain even-aged stocking guide levels.
White ash	Cleaning will maximize ash component but dominants will usually survive without treatment.	May need heavy release to avoid mortality due to suppression in tolerant mixture. Trees will resist epicormic sprouting.	Maintain crown position of crop trees. Maintain even-aged stocking guides or cut to 16 m^2/ha of basal area.
Red oak	Control competition with herbicide or fire within ten years.	Thin low-origin sprout clumps to best stem before DBH exceeds 5 cm. Suppressed stems respond to release but may produce epicormic branches.	Maintain even-aged stocking guide levels. Stop thinning at age 60 years.

mended in any case until dominant stems can be recognized. Mixtures of species such as black cherry, red oak, yellow birch, and white ash have benefitted from early release. However, ill-conceived treatments can delay natural pruning and promote epicormic branching, low forking, and sunscald, and otherwise adversely affect quality (Nyland and Marquis 1978). Traditional cleaning and weeding, where it can be justified, will eliminate undesirable species (such as aspen) and poorly formed individuals (such as sprouts). Sprout-origin red oak benefits from cleaning whereby clumps are thinned to the best single stem of low origin before diameter exceeds five centimetres.

Cleaning should be carried out only when necessary to maintain survival and stocking of potential crop-quality trees of the desired species of intermediate shade tolerance. Erdmann (1983) recommends cleaning yellow birch saplings when they constitute less than 50 per cent of stocking. The need is minimized, however, by regeneration techniques that achieve a higher proportion of preferred species. For example, where group selection and fall prescribed fire are used, 95 per cent of reproduction may consist of yellow birch, due to the selectivity of the reproduction technique. Such groups of saplings are usually in need, however, of liberation cuttings in which the original canopy gaps are enlarged as the regeneration occupies the opening. This usually occurs as part of a normal single-tree selection cut at the next cycle. This type of release is also appropriate where poor-quality veteran residuals occupy the site to the extent that they interfere with development of regeneration.

Crop-tree Release

If precommercial cuttings are considered, they should be applied only on a crop-tree basis (as characterized in Section 3.5.1, "Tending") to concentrate investment on the stems with the best quality potential. Subsequent treatments are designed to maintain designated trees with a favourable crown position until harvested. It is recommended that about 250 crop trees per hectare be selected in precommercial operations in southerly portions of the THWG range and perhaps 375 per hectare in the northern transitional forest. Limiting the release treatment to this level will greatly reduce expenses and carrying charges without adversely affecting yield. This will allow for future intermediate harvest and some mortality to sustain about 150 trees per hectare (a fully stocked stand) at the end of the rotation. Growth responses of THWG species to various precommercial crop-tree release treatments have been studied by Wendel and Lamson (1987); Lamson (1983); Erdmann et al. (1981, 1975a, 1975b); Hannah (1978); Lamson and Smith (1978); Trimble (1974); Erdmann and Peterson (1972); Marquis (1969); Drinkwater (1960); Conover and Ralston (1959); Church (1955); Stoeckeler and Arbogast (1947); Downs (1946).

In stands where site quality or location preclude intensive early cultural measures, the even-aged stocking guides (see Figure 8), that are not intended for precommercial use, may be used as rough approximations for stand treatment. In such cases, not more than 50 per cent of basal area should be removed during any treatment, and response levels can be expected to be less favourable than with more intensive methods.

Shade-tolerant species such as hard maple (and beech) can be carried for 30 years or more without treatment (preferably until removals are marketable) because they will not significantly deteriorate from moderately intensive inter-tree competition. This will promote clear-bole development at the expense of diameter growth, but the live crown ratio of potential crop trees should be maintained at levels above 30 per cent. Stems designated for removal should be felled or girdled if the operation is precommercial.

A similar approach can be applied to the semi-tolerant (inelastic) species such as yellow birch, but considerably more attention must be given to maintaining adequate live crown ratio (greater than 30 per cent) on the potential crop trees. Occasionally, this may be a problem in overstocked stands or in cases where overstory removal was significantly delayed, resulting in crown recession by age 25 years, which may not be recovered even after release. In these instances, precommercial crop-tree selection and release may be an option. Potential crop trees can be effectively released prior to extreme crown recession by freeing the crown ("complete crown release") through removal of neighbours that restrict crown expansion (Erdmann 1983). A similar procedure, called "crown touching," removes any tree (except another crop tree) whose crown touches the crop tree or overlaps above or below it (Lamson and Smith 1987). No trees are removed unless doing so will benefit a crop tree. Following crown thinning, diameter growth rates often will be twice that of untreated stems and will be concentrated on better-quality trees. Neither basal area nor spacing is given prime importance in young stands. The correct selection and release of potential crop trees is the main basis for treatment. Stem quality will not usually be affected (because of the previously rapid self-pruning) as long as the crowns close again prior to the first commercial thinning.

Where economically feasible to release greater numbers of stems per acre, the "D + (Imperial unit)" rule may be useful. Stoeckeler and Arbogast (1947) used "D + 2" as a rule to determine release radius in young northern hardwoods. In this method, all competing trees are removed within a radius equal to the crop-tree DBH + 2, numerically substituting feet for inches (i.e., a DBH of two inches would give a release radius of four feet.). The metric equivalent to this rule is approximated by the equation:

$$\text{Radius (m)} = 0.605 + 0.12 * \text{DBH (cm)}.$$

A similar (Imperial unit) rule for oak (D + 1) has been recommended by Johnson and Godman (1983).

While using chainsaws to cut competing trees is considered cheaper than using herbicides, release effects may be short-lived if vigorous resprouting occurs. In such cases, the technique of Wendel and Lamson (1987) is appropriate; it involves administering a 20 per cent aqueous solution of glyphosate by stem injection at intervals of 4 cm edge-to-edge around the base of all stems larger than 2.5 cm in basal diameter. Applying 1.5 ml of solution per incision effectively controls resprouting of target stems.

In oak regeneration, cleaning can be accomplished using prescribed fire. Two burns, four years apart, effectively control sprout competition while the oaks are able to resprout and grow without serious difficulty (Nyland et al. 1983).

Market conditions and the degree of stand development often dictate which thinning methods are possible. The advantages of early thinning do not occur before crowns close, inter-tree competition becomes important, and crop trees self-prune to desired clear length. The first practical thinning in hardwood stands is often postponed until they reach "commercial" pole size (15 to 20 cm in DBH and 7.5 to 10 m in clear length), and this is usually impractical before age 40 years. White ash, yellow birch, and black cherry usually respond best to thinning before age 40 and thus may require precommercial operations. Being "inelastic" species, they will not respond favourably to release from the crown-depleting effects of crowding at later ages. On the other hand, hard maple stem form usually benefits from delayed release; it can respond favourably even after considerable suppression. Hibbs and Bentley (1984) developed a growth model for red oak (perhaps also applicable to other semi-tolerant THWG species), which suggested that thinning before age 45 would reduce potential financial returns, due to the trade-off between merchantable height and diameter growth rather than to the cost of precommercial thinning. The value lost in merchantable height (from lack of self-pruning) is not compensated by the value gained in additional diameter growth induced by thinning. A rotation of about 95 years would maximize returns. The timing of the first thinning is therefore a compromise between shortening the rotation and optimizing the effects on bole quality and value.

When the average stand diameter reaches "commercial" size in the southerly range of the THWG (15 cm DBH with about 23 m^2/ha of basal area at 40 years (Murphy, no date b), the stocking guides provided by Tubbs (1977b) can be used to regulate stocking levels. When adjacent crowns touch, resulting in lower branch mortality, the "average" line of the stocking guide has been reached, representing the best balance between individual tree growth and quality development (Erdmann 1987). In pole stands, basal area of trees 10 to 15 cm DBH and larger should not be reduced to less than 14 m^2/ha or left at more than 20 m^2/ha. Reducing density by 30 per cent will seldom lead to sunscald or epicormic branching. Light appears to play an insignificant role compared to crown position and size in the development of epicormic branches (Books and Tubbs 1970). In mixed species, stands should be cut from below to 60 to 70 per cent *relative density*, and thereafter, thinnings to remove about 20 per cent relative density should be scheduled at 15-year intervals until final harvest (Stout 1987). By the age of 60 years in southerly portions of the range, average stand diameter should have increased to 25 cm DBH and thinning should be done to maintain growth on the best stems and to prevent crown depletion (Murphy, no date b). Stands in the northern transitional forest may require additional time (up to 25 years) to attain this condition (Bruce and Heeney 1974). For best growth and quality development, Erdmann (1987) recommends leaving increasing amounts of basal area and decreasing numbers of trees as stand average DBH increases, to maintain stocking guide levels. The technique of "rule thinning" developed by Rogers and Johnson (1985) may be useful for oaks and other species in meeting stocking goals during thinning treatments.

In small sawlog-size stands (25 to 30 cm DBH), selective thinning can be carried out to free codominant crop trees from their two most important crown competitors. This activity should not remove more than one-third of the basal area. In the later, mature stages of even-aged management, a few overstory trees can be cut to favour crop-tree growth without seriously

reducing total volume production, but this approach should be limited to salvaging high-risk, cull trees without creating large canopy holes. Stocking should not be reduced below 18 m^2/ha, nor should more than 28 m^2/ha be retained. The last thinning should leave only enough high-quality trees (about 150 final 45 cm DHB trees per hectare) to completely utilize the site.

With regular crown release and thinning schedules, yellow birch 45 cm DBH and of veneer grade can potentially be grown in 87 years. Without this tending, it could require an additional 60 years (Erdmann 1987). Similarly, Nyland and Marquis (1978) estimate that proper treatment should produce hard maple with a DBH of 50 cm in 80 years with a mean stand diameter of 38 cm in the northeastern United States.

In even-aged management, the final thinning (at about 80 years) would be in the form of a reproduction cutting, usually a type of shelterwood. The final liquidation of the stand would occur when the new crop is successfully established.

3.5.1.3 Converting Even-aged to Uneven-aged Stands

Studies of cutting methods in second-growth stands in Wisconsin by Erdmann and Oberg (1973) have produced recommendations for developing uneven-aged stands from second-growth even-aged stands of shade-tolerant hardwoods (Erdmann 1987; Godman 1986). Most even-aged stands are overstocked with polewood and understocked with sawlog trees compared to the uneven-aged guides produced by Crow et al. (1981) and Arbogast (1957). Therefore Q-values of 1.6 to 1.7 (for 5 cm DBH classes) are more appropriate as a guide for the first cut. With recommended treatment, a Q-value of 1.3 can be achieved. It is suggested that marking concentrate on balancing basal area stocking in three sawtimber sizes rather than applying only a single stocking level of 14 to 20 m^2/ha (12 cm DBH and larger). In situations where management objectives require a conversion, the following procedure modified from Erdmann and Oberg (1973) may be applied:

- Starting with a 50-year-old polewood stand with crop-quality trees averaging 15 to 20 cm DBH and with 7.5 to 10 m of clear length, structure and quality should be quickly developed by crown release and should favour about 125 of the best dominant and codominant crop trees per hectare. Crown release a radius of two metres beyond the crown perimeter of pole-sized crop-trees or remove two important poor-quality crown competitors next to small sawlog-size crop trees. Ideal full occupancy of crop trees would space them about 10 m apart, but only good crop trees should be selected. Do not cut good crop trees unless competing with other crop trees.

- Remove high-risk, cull, and defective overstory trees.

- At each cutting, create 10 to 12 crown openings per hectare, each about 10 m in diameter, by removing any large overmature trees or groups of poor-quality poles. Make a patch cut if possible to remove small stems down to 5 cm DBH. This will encourage establishment and

recruitment of tolerant-species regeneration to ultimately develop into a single mature tree in each gap.

- The first thinning in 12 to 23 cm DBH pole-sized stands should be from below (beneath crop trees) to the *minimum* stocking level of Tubbs's (1977b) guide (see Figure 8). Such cuts are heavy enough to get a good growth response but may be precommercial if markets for small material do not exist. In this case, initial entry into the stand may have to be postponed to age 60 years if investment opportunity is not available. This thinning should bring the stand back to 14 m^2 of basal area per hectare (DBH 10 cm +).

- For optimum quality development, the second thinning should be delayed for about 20 years until crown closure develops and lower branch mortality (self-pruning) occurs on the crop trees. This second cut should concentrate via selection on improving quality development in the three sawtimber size classes as well as creating canopy gaps for regeneration. This cutting should reduce stocking to the *average* level of Tubbs's (1977b) guide, which will depend on the average stand diameter.

- The third cutting should be according to selection stocking guide recommendations. A 45-year-old even-aged stand should be fully converted to selection after three cuts.

3.5.1.4 Hemlock-Hardwood Stands

Tubbs (1977b) recommends, for stands overstocked with sawlogs in the Lake States, that basal area first be reduced to 23 to 35 m^2/ha. A salvage cut should be planned within five years in overmature stands (post-logging decadence in hemlock). Subsequent cutting should reduce stocking to 18 m^2/ha (24 cm DBH and larger) on a ten-year cycle.

3.5.1.5 Pruning

Natural or self-pruning in tolerant hardwoods will be adequate at recommended residual stocking levels (see Section 2.5, "Stand Stocking and Structure") to shed all limbs on the lowest two logs of crop trees. In areas of good access, the stem quality of high-value species in understocked stands can be improved by artificial pruning (Heeney 1974). Murphy (no date a) suggests situations in which hardwood pruning may be justified, including (i) plantations with only 1700-4000 stems per hectare, (ii) sporadic regeneration volunteering on agricultural land, and (iii) 15- to 30-year-old woodlots in which stocking is low (500-1700 trees per hectare), usually resulting from a pasturing history. The objective of deliberate pruning is to produce clear wood (knot-free) on the bole of crop trees on a shorter rotation than would be possible through natural pruning.

Pruning is a long-term investment that should be performed only on potential crop-quality trees of dominant or codominant crown class. It may return 8 to 12 per cent on investment, especially

if trees are at least 15 cm DBH when treated. It is usually coupled with thinning to stimulate growth rate, callousing, and upper crown development. Some studies suggest profitability if growth rings can be maintained at three rings per centimetre or better (Smith 1962). Methods of evaluating the economics of pruning are given by Smith (1954b).

Unlike conifer management, in which a specified number of trees per hectare are pruned, hardwood management involves pruning on an individual-tree basis in which only a few (5 to 10) low branches or early forks are removed from each tree (Skilling 1959a, 1959b). It is recommended that only the butt log be pruned (i.e., to a height of 5 m) for best returns and that this pruning should not exceed 50 per cent of total tree height. Removal of dead lower branches has no effect on growth rate. Pruning should be delayed for two or three years after thinning to allow a build-up in crown vigour to suppress epicormic branching (Godman and Marquis 1969).

Tendency to produce epicormic branches after pruning or other disturbance varies with species (Trimble and Seegrist 1973; Smith 1966; Blum 1963; Skilling 1957). In oaks, there is some evidence that epicormic branching may be genetically controlled, and Carvell (1971) suggests that oaks exhibiting this tendency should not be pruned. Both black cherry and red oak are very prone to epicormic branching. Hard maple and beech are less affected and white ash rarely produces epicormic branches following pruning. Yellow birch tends to produce more epicormics than hard maple. Most affected species are less susceptible in stems of dominant or codominant crown position, especially when the crowns are well developed. Red oak may show a greater susceptibility on poorer sites (Site Index 18) compared to better sites (Site Index 24). Artificial pruning does not tend to increase final clear length in unthinned stands of hard maple, but can significantly increase clear length in thinned stands by 30 per cent (Conover and Ralston 1959).

3.5.1.6 Stump Sprouts

Stems originating vegetatively as coppice or sprouts from cut stumps or fire-killed tops can produce crop-quality stems and high-value products, often on shorter rotations than seed-origin trees. However, they must be selected and tended appropriately to achieve their potential. A good overview of tending methods for hardwood sprouts is given by Stroempl (1983).

Sprouting ability differs among species and often varies with parent-tree size, age, and vigour, stand density, and years since disturbance. Among the THWG species, black cherry is the most prolific sprouter, significantly greater than white ash, red oak, and hard maple in respectively decreasing order. Yellow birch sprouts poorly enough to be considered a non-sprouting species. From a regeneration point of view, white birch and ironwood, considered undesirable species, have more prolific sprouting ability than all except red oak and black cherry (Powell and Tryon 1979; Perala 1974; Solomon and Blum 1967).

In hard maple, sprouting ability and sprout development are influenced by stand age, parent-tree size, and stand density. In cutover mature stands, the percentage of stump sprouting declines significantly with parent-tree diameter, stand density, and age of cutover. Sprout survival also decreases with tree size and years since cutting. In second-growth stands and young poletimber,

neither stand density nor tree size influences sprout production (Church 1960). Clear cutting stimulates prolific sprouting in maple (Tubbs 1977a). Solomon and Blum (1967) found that the vigour of sprout production varied inversely with the age of the parent tree. Although hard maple has significant sprouting ability, the desirability of extensive areas of maple coppice is considerably less than that of red oak, black cherry, or white ash. Nevertheless, adequate tending can produce good-quality stems from maple coppice and it can serve a useful role in areas understocked with trees of seed-origin.

In red oak and black cherry, however, the proportion of stumps that sprout, the number of sprouts per stump, and dominant sprout height are not correlated with parent-tree vigour or parent-tree DBH according to Wendel (1975). Keetch (1944) notes that sprouting in oak is more prolific following fire in a stand of small trees (DBH less than 13 cm) than in polewood- or sawlog-size stands of Appalachian hardwoods.

Sprouts originating from seedlings or saplings usually produce acceptable stem quality. Those originating from larger or older trees usually are not acceptable for high-quality timber production because of poor survival, poor form, and probability of stump rot. Large stubs of dead companion sprouts with mature-wood connections usually result in butt rot in the surviving sprouts (Tubbs 1977a). Oak stump sprouts smaller than 7.5 cm DBH can be thinned without risk of decay. Clumps greater than this size can be thinned if they have low-origin "U-type" junctions. Stems with V-type junctions or from older stumps should be either completely cut or left entirely (Roth 1956). Sprout clumps arising after fire usually originate at the root collar. Using prescribed fire as a tending tool for red oak will therefore tend to produce oak sprouts of favourable origin and with good quality potential.

The difficulty of satisfactorily regenerating red oak increases the importance of using sprout material as prime growing stock. Johnson and Godman (1983) suggest that, under even-aged management, oak sprout clumps are good choices for precommercial thinning; however, these advantages do not materialize unless the clumps are selected properly and thinned early.

Stroempl (1983) noted that it is most practical to thin to two or three sprouts per clump before age 20, later reducing the clump to a single stem. Early clump thinning to a single stem will maximize diameter growth of individual stems, depending on stand density level, crop-stem diameter, age, and relative basal area (i.e., ratio of stem basal area to clump basal area) after thinning, and site quality. It is necessary to remove competitors every ten years to sustain maximum growth (Johnson and Rogers 1984). However, large sprouts that occupy about 50 per cent of the total basal area of the clump grow at approximately the same rate whether thinned or unthinned (Johnson and Rogers 1980).

An approximate thinning radius for sprout oak, given by Johnson and Godman (1983), is known as the "D + 1" rule; it approximates the maximum tree-area growing-space requirement for red oak and is equivalent to the "B-level" line of the oak model developed by Gingrich (1967). A growth simulator known as "COPPICE" has been developed by Rogers and Johnson (1982); it accurately predicts ten-year diameter growth for red oak in Wisconsin.

Johnson and Godman (1983) suggest the following guidelines for thinning oak clumps:

1. Select stands on better sites.

2. Thin clumps when they reach 5 cm in DBH and definitely before 7.5 cm DBH.

3. Select the largest single stem that is well attached to stump at or below ground level and not connected to another stem.

4. For larger stems (greater than 7.5 cm DBH), the lower 5 m of stem should

   (a) be free of sweep, crook, seams, fork, or decay;

   (b) be free of V-connections with other stems; and

   (c) show little evidence of epicormic branching.

5. Thin around crop stems to provide adequate growing space and to optimize growth and quality (use "B-level" stocking guide).

6. Early clump thinning of red oak to one stem should produce a commercially mature stem (in Wisconsin) 20 years earlier than for trees of other origin.

Stroempl (1983) gives additional suggestions for encouraging the development of sprout clumps of northern hardwoods:

- To encourage sprouting, cut parent trees in dormant season.

- Recut high stumps closer to the ground to encourage more sprouts to originate belowground.

- Cut damaged or otherwise unsuitable advanced growth during cleanings to produce desirable seedling sprouts.

3.5.2 Protection

The investment made in intensively managing the forest under the selection or the shelterwood systems should be protected by ensuring the long-term quality development and productivity of the treated stands. Three of the major concerns in the THWG are (i) logging damage in partially cut stands, (ii) the development of hardwood decline, and (iii) insect and disease outbreaks.

3.5.2.1 Logging Damage

Some degree of physical damage to residual stems during the harvesting operation in partially cut stands is inevitable. The types of injury that may be encountered involve (i) bole wounds

caused by bark scraping or peeling, (ii) root breakage, (iii) crown damage resulting from branch breakage, (iv) stem breakage, and (v) bending or tilting of trees from the upright position. The first two of these (*wounding*) are usually attributable to log-skidding operations while the latter three (*damage*) are associated with tree-felling. Wounding usually results in volume and value (quality) losses over time from infection and decay processes. Damage will result in loss of growth due to crown reduction, mortality from stem breakage, and top rot from branch stub infection, as well as a high risk of windthrow or loss of bole-form due to unstable (leaning) characteristics.

Controlling logging damage is critical in implementing the selection system because trees must be carried for long periods and to large sizes. Value potential, as justification for selection, is compromised if harvesting procedures are not well planned and supervised to minimize damage.

Overviews of the incidence and severity of logging damage in partially cut THWG stands are given by Nyland et al. (1976), Nyland and Gabriel (1971), and Hesterberg (1957a). Table 19 summarizes the results of some logging-damage assessments carried out in hardwood stands.

Ohman (1970) evaluated ten-year-old skidding wounds on yellow birch and hard maple and found that it was possible to predict the probability of value loss but not to predict the actual monetary loss. A wound on the poorest grading face would have little effect on grade while the same wound on any of the other three grading faces would affect grade and value. Also, a wound resulting in *volume* loss on a low-quality tree would cause relatively little *value* loss, but a similar wound on a veneer-quality tree could reduce its value by 50 per cent. Predicting high-risk trees using wound characteristics is possible and losses can be minimized by harvesting these trees at the next cutting cycle. In hard maple, especially, the roles of tree vigour, wound healing and inherent defense mechanisms (e.g., "wound barrier" formation) are very crucial to the recovery of crop trees from damage.

Heij and Leek (1981) noted that after six years the decrease in value of the residual stand caused by damage amounted to about three-quarters of the direct skidding costs. Since most logging equipment has been designed to minimize logging costs rather than damage to trees and soil, responsibility for damage control rests with the planning of the harvest and the skill of the machine operator. Techniques for efficient and safe wheeled-skidder operation are given by Hartman and Gibson (1970).

In addition to differences attributable to logging technique, much of the damage profile in any study (i.e., sapling/polewood/sawtimber injury) is probably related to original stand characteristics and history (e.g., structure, density, configuration, terrain, etc.). These factors should be recognized and considered when implementing any harvesting or tending operation.

Damage Avoidance

While in general, the larger the equipment used, the larger the potential impact on the forest, the extent of logging damage is determined primarily by the way a machine is used rather than by its type and size. If control techniques are used, concern over the size of machinery is much

TABLE 19: Some Results of Logging Damage Assessment in Partially Cut Stands of the THWG

AREA	OBSERVATIONS	SOURCE
Lake States	30% of main-trunk logging scars on hard maple produce serious defect in 15 to 20 years.	Godman (1957)
Lake States	Cull development in hard maple is related to scar width and time since wounding. Two-thirds of wounds occur in butt log.	Hesterberg (1957a)
Lake States	In 10-year-old wounds, loss of value was 2.1% (log) and 0.6% (lumber). 66% of wounds > 325 cm^2 resulted in lowered value. Yellow birch developed more defect than hard maple.	Ohman (1970)
Lake States	Tree-length tractor and arch skidding injured 3x as many trees as ground skidding log-lengths. Ground skidding increased the incidence of root wounds.	Benzie (1959a)
Lake States	Excessive damage occurred with tree-length logging with rubber-tired skidders.	Meyer et al. (1966)
Lake States	Winter logging in shelterwood cut destroyed 35% of advance growth. After three years, stocking of regeneration still exceeded minimum stocking levels.	Jacobs (1974)
Lake States	Felling large cull trees damages about 1 m^2/ha of basal area (about 0.09 m^2/tree). Considered to be excessive; recommend girdling or poisoning as alternative.	Arbogast (1950)
Virginia	20% of residual trees were damaged and 12% of pole-wood were destroyed using tree-length tractor skidding.	King (1963)
Central States	Tree-length harvesting caused more damage than log-length harvesting. Directional felling could minimize damage to 10% or less.	Deitschman and Herrick (1957)

TABLE 19 (cont.)

Area	Observations	Source
New York State	Logging can injure 30% of residual trees, 20% in a major fashion. Felling causes twice as many injuries as skidding. 70% of trees adjacent to major skid trails were injured (60% in a major way).	Nyland and Gabriel (1971)
West Virginia	In selection stands after three cutting cycles, trunk wounds affected 12% of residual basal area. Logging damage reduced basal area by 6% due to tree destruction (mostly less than 12 cm DBH).	Lamson et al. (1985)
Algonquin Region	Shelterwood method that harvested 43% of basal area damaged 16% of residual basal area. Felling tended to injure polewood, while skidding affected saplings. Damage level was only 50% of that found by Nyland et al. (1971).	Irwin (1972)
Algonquin Region	In growing season, 26% of residual basal area and 25% of trees were injured (76% major). In dormant season, 12% of residual basal area and 14% of trees were injured (75% major).	Walsh (1980)
Algonquin Region	20% of original basal area was injured, 60% seriously. Skidding caused twice as many injuries as felling. Calculated volume loss was 8 m^3/ha; 30% of damage occurred on crop-quality trees.	Johnson (1978)
Algonquin Region	Logging injured 32% of precut basal area (25% wounded and 7% damaged). 49% of residual basal area was affected, ranging from 14% to 91%. Injury severity was directly related to cut intensity and degree of skidding activity.	Stokes (1983)

diminished. Damage can be controlled if operator training and education in terms of forest management objectives is done, and if the job is well planned and supervised. Positive personal attitudes are essential.

The importance of logging damage in selection management will increase as tending and harvesting progress over time, and as cutting cycles are shortened, increasing the frequency of re-entry and the associated risk of damage to the residual crop trees. With cull removed, crop trees selected, and structure developed, future damage will affect better-quality trees. Thus current enhancement of logging skills wll pay dividends in the future.

The following damage avoidance techniques are recommended:

- Avoid logging in very wet weather to avoid site degradation. Harvest in winter when the ground is frozen or on coarser-textured sites. Use a rubber-tracked vehicle if necessary to log in wet weather.
- Avoid logging in spring (May through June) when bark is in the "sap stage" and relatively loose as a consequence of cambial activity.
- Plan removal cuts in shelterwood for winter so that snow will protect advance growth.
- Plan and mark out skid-trails in advance.
- Use existing trails where possible (unless they support valuable volunteer regeneration).
- Make new trails widely spaced and as short as possible. Trails should be as straight as possible, with gentle curves and easy grades.
- The angle of trail intersections should be small (30° maximum).
- Have the feller and the skidder operator work as a team.
- Locate trails close to trees marked for removal to act as "bumper" or "rub" trees to keep the hitch of logs aligned during skidding.
- Similarly, leave "swing" or "pivot" trees at turns and trail intersections.
- Start the harvest at the back of the cut and skid to main trails to avoid detours around slash.
- Use directional felling. Fell trees with tops away from the skid trail to avoid swing damage, at a 20° to 30° angle to the axis of the trail. Fell into new gaps if available.
- Restrict skidder size to between 80 and 120 hp. Ensure that the skidder has at least 25 m of cable on the winch.

- Winch logs to the skidder rather than backing the skidder to the stump to reduce the need for spur trails. Orient the skidder toward the main trail before hitching to chokers.

- Do not skid trees with tops intact. Process shortwood at the stump if necessary. Suggest a maximum load length of seven metres.

- Skid at lowest possible angle to the contour lines of the terrain.

- Cut bumper and swing trees last.

- Strive to limit logging damage to 10 per cent or less of the stand.

- Communicate these techniques to the operator.

Damage Recovery

One of the advantages of the selection system that affects the impact of modest logging damage is that opportunities exist at each harvest cycle to "correct old mistakes" by harvesting damaged trees. In regulated stands, perhaps 37 polewood and 37 sawtimber trees per hectare might be harvested at 10 to 15 year intervals. If extensive damage occurs, there may be too many injured trees to harvest within the structure and stocking guidelines. In addition, damaged trees are eliminated as marking choices for residual trees in the next cut, thus decreasing chances to improve structure. Tables 20 and 21 outline criteria for assessing logging-damage severity.

Rot from wounds less than 325 cm^2 in area will not usually cause serious loss in ten years. Yellow birch will develop cull faster than hard maple, and red oak will be comparatively resistant to cull development. The following guidelines from Ohman (1970) will help minimize future losses from logging damage.

- At the end of the current harvest, evaluate damaged trees using log-grading rules. Harvest any trees that will deteriorate within the subsequent cutting cycle. Do this cautiously in order to maintain marking and stocking objectives.

- In the subsequent harvest, cut all trees, where possible, that have stem wounds larger than 325 cm^2.

- At the same harvest, cut yellow birch trees with root wounds larger than 325 cm^2 within 1.2 m of the stem and in contact with the soil.

- Remove trees with the oldest and largest unhealed wounds in each subsequent cut.

- Examine hard maple trees with root damage for signs of decline caused by sapstreak disease.

TABLE 20: Logging Damage Risk Classification for Hard Maple (Adapted from Hesterberg [1957b])

Injury Type	Width		10-year wounds		20-year wounds	
			Average Deduction (from log scale)*			
	cm	in	m^3	fbm	m^3	fbm
Stem	< 10	< 4	0	0	0.051	10
Scars	15 20 25	6 8 10	0.051 0.101 0.152 to cull	10 20 30 to cull	0.101+ 0.177 0.254 to cull	20+ 35 50 to cull
Branch	< 10	< 4	0	0	0	0
Stubs	> 10	> 4	0.025 - 0.041	5.8	0.076 - 0.101	15 - 20

*Converted from Imperial units using Algonquin Forestry Authority convention:
1 fbm = 0.00507 m^3

TABLE 21: Criteria for Judging Major Injuries to Hardwood Trees (Adapted from Nyland and Gabriel [1971])

Injury Type	Wounds Judged as Major Injuries
Bark abrasion	Bark scuffed off, exposing 580 cm^2 or more of wood surface for yellow birch, or 968 cm^2 or more of wood surface for other species.
Broken branches	Branches larger than 7.6 cm in diameter broken from the tree.
Root damage	Roots exposed over 25% or more of the ground surface area within the drip line of the tree crown.
Broken off	Main stem broken off, destroying the tree and most or all of the crown.
Bent over	Tree partly or entirely uprooted, noticeably tipped out of its normal growing position.

3.5.2.2 Hardwood Decline

Forest decline involving hardwoods has been documented in North America since the early 1900s (McIlveen et al. 1986). It is a complex disease caused by the interaction of a number of interchangeable, specifically ordered abiotic and biotic factors that produce a gradual deterioration, often ending in the death of trees (Manion 1981). The syndrome usually involves at least three factors, one from each of (i) predisposing, (ii) inciting, and (iii) contributing categories. The central hypothesis is that stress of biotic or abiotic origin alters the tree's health and renders it susceptible to further loss of vigour. Disease organisms ultimately attack the weakened trees, resulting in their demise (Houston 1981).

Visual symptoms of stress and decline are outlined by Skelly et al. (1987) and Malhotra and Blauel (1980). Among the most obvious symptoms seen in Ontario are the following:

- abnormally small and chlorotic foliage;
- premature fall colouration;
- late spring bud-break;
- early leaf abscission;
- progressive crown dieback starting with fine twigs at periphery and working inwards;
- wounds heal slowly;
- bark eventually sloughs off;
- increased epicormic sprouting (in tufts);
- loss of starch (food) reserves; and
- slow growth.

Historically, decline has affected a variety of species under varying circumstances. Individual episodes of dieback have been noted for white ash, red oak, beech, hard maple, yellow birch, and hemlock in the past. The current appearance of decline in Ontario commenced in the late 1970s, fluctuating in intensity with time and affecting many species. Decline is not unprecedented in Ontario but the current situation is unusual in the variety of sites and species affected.

The Ontario Ministry of the Environment (MOE) conducts annual surveys of forest health. For each location sampled, a "decline index" is calculated by species based on the percentages of dead branches, chlorotic leaves, and undersized leaves in the crown. The resulting decline index scale varies from 0 (healthy) to 100 (dead).

On the basis of such analyses, McLaughlin (1987) assessed the mean decline index for 16 hardwood species in Ontario in 1986. In decreasing order of health (increasing mean DI) among the 16 species, hard maple ranked third (DI=12.4), beech ranked fourth (DI=13.8), white ash ranked sixth (DI=18.7), yellow birch ranked seventh (DI=20.5), red oak ranked ninth (DI=22.1), and black cherry ranked thirteenth (DI=30.5). In relative terms, a DI-value lower than 12.5 would be considered to constitute a healthy to a "trace-decline" condition, a DI-value between 12.6 and 17.5 would be considered light-to-moderate decline, and DI-values greater than 17.5 would be rated as high-to-severe decline.

These average values vary from year to year, fluctuating with a variety of current factors. The decline severity for all species considered together also varies with location in Ontario. In 1986, mean decline index values associated with the forest regions and sections of Ontario (Rowe 1972; see Figure 1), were calculated as follows (McLaughlin 1987):

- Decline index is highest (17.3) in Georgian Bay (L.4d); relatively high values are also found in Quetico (L.11), Algoma (L.10), and Sudbury-North Bay (L.4e). Moderate values are noted in Niagara (D.1), Algonquin-Pontiac (L.4b), and Middle Ottawa (L.4c). Comparatively low values (less than DI=14) are seen in Upper St. Lawrence (L.2) and Huron-Ontario (L.1).

While the causal factors for decline have not been clearly defined, the epidemiology appears related to known stress events. Climatic episodes (thermal stress, precipitation stress) and insect defoliation (especially from forest tent caterpillars and oak leaf shredders) appear closely related to episodic symptom development. Somewhat similar symptomology seems to have been elicited by different inciting agents in different locations and species. Ash dieback has been triggered in the past by drought; beech, maple, hemlock, and oak decline can be precipitated by insect defoliation; and birch dieback may have been associated with climatic stress. Secondary agents such as *Armillaria mellea* often accelerate symptom development by causing root rot. The maple decline situation in Ontario was relatively stable during the 1985-87 period, even showing improvement in some locations. The severe drought and insect infestation in 1988, however, caused the condition of maple to worsen significantly in previously affected areas.

Air pollutants such as sulphur dioxide, nitrogen oxides, and ozone are additional stresses imposed on an already-stressed ecosystem. The nutrient-leaching effects of acid deposition are well documented (Foster 1985; Foster and Nicolson 1984). A major portion of Ontario receives high annual loadings of acidic precipitation and sensitivity maps have been prepared to rate the soils and bedrock of Ontario in their ability to reduce the acidity of atmospheric depositions (Cowell 1986). Almost 32 per cent of Ontario consists of highly or moderately sensitive areas that receive potentially damaging annual loadings of wet sulphate. The most critical of these is the Muskoka region, where the impact is reflected in a relatively high decline index rating.

While forest managers cannot control most of the inciting factors associated with forest decline, they must deal with the condition in prescribing silvicultural treatments. Choosing appropriate sites and recognizing decline symptoms not attributable to normal aging processes or lack of proper management in the past are critical. In a "decline scenario," one option to be considered

should always be delaying treatment until a proper diagnosis and remedial prescription can be made by consultation with appropriate knowledgeable authorities. On the other hand, some planning procedures should take account of the probable effect of predictable insect infestations on the health of species growing on sites sensitive to both climatic and pollution stress. Perhaps the best approach is to concentrate intensive management on the sites least sensitive but most appropriate for the species (McLaughlin 1987).

THWG stands showing discernable decline symptoms of concern to the forest manager may be referred to the Phytotoxicology Section of the MOE Air Resources Branch for possible evaluation.

3.5.2.3 Insects and Diseases

Managing insect and disease pest problems is to some degree an intrinsic part of normal silviculture. The process of repeated, frequent tending and stand improvement operations in selection management, with its associated discrimination against poor-quality diseased, over-mature, and declining trees, tends to upgrade vigour and reduce the incidence of such diseases as decay and canker and of insect damage such as that caused by maple and oak borers. Insect infestations tend to be cyclical and predictable from monitoring conducted by the Forest Insect and Disease Survey of Forestry Canada, who advise periodically on developing problems. Overviews of pest problems associated with the THWG can be found in McGauley and Kirby (1985), Hepting (1971), and MacAloney and Ewan (1964), and in Section 2.3 under "Damaging Agents" for each species.

3.6 Management Strategies

The forests of Ontario show a great diversity of age, quality, and productivity. They are often mature, of variable quality, and underproductive because of their history. Typically in the THWG, the stands are uneven-aged and mature. Often they were high-graded (i.e., subjected to "selective" or "diameter-limit" cuts) in the past before regulated harvest; this approach depleted quality without appreciably improving growth. Other stands reverted to even-aged second growth because of heavy (clear) cutting or natural catastrophe (fire, insects, etc.).

In the forests of Site Regions 5E, 6E, and 7E, many hardwood stands developed in response to extensive logging for white pine about a century ago. These originally pine stands were often established as a result of wildfire, and the best stands were those initiated in this way on the best sites. Other good hardwood stands occurring on fertile sites were promoted by light logging for mature hardwoods about 50 years ago (during the establishment of the hardwood lumber industry), which acted as a modest thinning. In the last two decades, regulated harvesting using timber-marking procedures controlled by silvicultural prescription and based on scientific knowledge has begun to stabilize the THWG forest estate into a predictable, productive system. This shift has been facilitated by the development of markets for low-grade products such as pulpwood, canter logs, and fuelwood.

Historically, logging has led to situations in which species have been selectively eliminated from stands without adequate regeneration, proportion of cull has increased, and stand growth has been depressed. Such shortfalls in anticipated supply may be remedied in part by a more complete utilization of available supplies but will be avoided more effectively, in the long run, by more intensive management practices, using technology that is now available.

In circumstances of strong demand and high lumber prices, forests of lower quality or of more costly access may be harvested. Conversely, when demand is weak, readily accessible, high-yielding, high-quality stands will be not only preferred, but essential for economic survival. While the biological productivity optimum is referred to as the technical rotation, for commercial reasons stands may be cut later to increase tree size for newer products, or earlier to reduce the investment period, though at the expense of tree quality.

Assigning areas to either an "intensive" or a "basic" management strategy will be governed by the principle of best return on investment. Areas are termed "prime sites" according to four criteria:

1. *Site productivity* is defined by soil, climatic, and biotic characteristics interacting with forest cover. In many cases, especially with high-quality hardwoods such as hard maple, red oak, and yellow birch, these sites are specifically selected for their associated rapid growth and high yield. However, for other species (e.g., hemlock), a less-productive site might be chosen because of less-vigorous competition in the establishment phase.

2. *Access*, which involves road infrastructure and transportation distances from mill sites, will affect the economic return on even the most productive sites. In the partial-cutting systems used with THWG species, however, the periodic re-entry into stands and the continuous use of the road networks often maintained for other purposes (e.g., recreation, integrated resource management activities, etc.) will reduce the costs of regenerating, tending, and harvesting. In the sawmilling industry, the development of technology for portable high-quality sawmills could revolutionize the industry and reduce speculation about mill location and could modify the definition of "prime site" as it is currently related to fixed mill sites.

3. *End-product value* will affect the economics of prime site location because of the value-added advantage of hardwood components remanufactured into consumer products. However, the prime consideration for quality production, and hence value growth, will be site quality (i.e., "Prime Land"), since the quality potential of the forest is severely constrained by site potential. However, even on the best sites, the degree of difficulty offered by the sites and the funding required to offset such problems in achieving a management objective must be considered. The higher value return should allow longer routes to access these better sites and support better road systems to sustain periodic re-entry into the stands.

4. *Time* affects the financial analysis of any forest investment. Interest rates and inflation factors must be considered in selecting the location and level of forest management. The attainment of financially mature diameters will be accelerated by prescribing proper

silvicultural systems and schedules and by selecting adequate sites to realize value-growth targets.

Because of the quality of sites and the access infrastructure in southern Ontario, most THWG stands are capable of justifying intensive silviculture.

Industry requires a predictable supply of wood of suitable quality, quantity, and location. Management practices for the THWG initiated on prime sites using appropriate prescriptions should assist this requirement by improving growth rates, quality parameters, volume production, and the frequency of periodic economic return. The allowable harvest will more closely approach the maximum allowable depletion when cull is reduced and damage losses are minimized. While producing wood to maintain a viable forest industry is the inevitable driving force behind the forestry program, managing Ontario's forests for other uses to ensure their proper place in the natural environment is an equally important responsibility. This will require an integrated multidisciplinary workforce to ensure that all forest values are maintained.

REFERENCES CITED

Aber, J.D., J.M. Melillo, and C.A. Federer. 1982. Predicting the effects of rotation length, harvest intensity, and fertilization on fiber yield from northern hardwood forests in New England. *For. Sci.* 28: 31-45.

Allen, A.W. 1982. *Habitat Suitability Index Models: Marten.* FWS/OBS-82/10.11. Washington: Fish Wildl. Serv., U.S. Dep. Int.

———. 1983. *Habitat Suitability Index Models: Fisher.* FWS/OBS-82/10.45. Washington: Fish Wildl. Serv., U.S. Dep. Int.

Anderson, E.F., and G.A. McCormack. 1967. *Anchor chain scarifiers in Ontario.* Silvicultural Note no. 2. Toronto: Timber Br., Ont. Dep. Lands and Forests.

Anderson, H.W. 1982. Regenerating yellow birch with prescribed fire. In *Proc. of Soc. Amer. For. Conv. at Cincinnati, Ohio,* SAF Publ. no. 83-04, 168-72. Washington: Soc. Amer. For.

Anderson, H.W., and M.M. McLean. 1970. Value increase potential of various grades of sugar maple trees. Dorset: Research Br., Ont. Dep. Lands and Forests.

Anderson, H.W., and J.A. Rice. 1990. *A Tree-Marking Guide for the Tolerant Hardwoods Working Group in Ontario.* In press.

Arbogast, C., Jr. 1950. *How much does felling large cull trees damage the understory?* Tech. Note no. 337. St. Paul, Minn.: Lake States For. Expt. Sta., U.S. Dep. Agric.

———. 1956. *Basic principles of forest management in northern hardwoods.* Land O'Lakes, Wis.: North. Hemlock and Hardwood Manuf. Assoc.

———. 1957. *Marking guides for northern hardwoods under the selection system.* Sta. Pap. no. 56. St. Paul, Minn.: Lake States For. Expt. Sta., U.S. Dep. Agric.

Arend, J.L., and H.F. Scholz. 1969. *Oak forests of the Lake States and their management.* Res. Pap. NC-31. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Ashenden, G.A. 1957. Final report for 1956-57 scarification project, Staniforth Lumber and Veneer Licence, Kiosk Management Unit. Pembroke: Ont. Dep. Lands and Forests.

Auclair, A., and G. Cottam. 1971. Dynamics of black cherry (*Prunus serotina*) in southern Wisconsin oak forest. *Ecol. Monogr.* 41:153-77.

Babyn, M. 1983. Growth of an even-aged yellow birch stand. Project PI-12-064. Petawawa: Nat. For. Instit., Can. For. Serv.

Basham, J.T. 1973. *Hardwood management in southern Ontario: How extensive and important are stain and rot in living trees?* Inf. Rep. O-X-186. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.,

Basham, J.T., and H.W. Anderson. 1977. Defect development in second growth sugar maple in Ontario. I. Microfloral infection relationships associated with dead branches. *Can. J. Bot.* 55:934-76.

Basham, J.T., and Z.J.R. Morawski. 1964. *Cull studies: The defects and associated basidiomycete fungi in the heartwood of living trees in the forests of Ontario.* Publ. no. 1072. Ottawa: Can. Dep. of For.

Baxter, D.V. 1943. *Pathology in forest practice*. New York: John Wiley & Sons.

Beattie, M., C. Thompson, and L. Levine. 1983. *Working with your woodland: A landowner's guide*. Hanover: University Press of New England.

Bell, M.A.M., J.M. Beckett, and W.F. Hubbard. 1974. *Impact of harvesting on forest environments and resources*. Victoria, B.C.: Pac. For. Res. Centre, Can. For. Serv.

Benzie, J.W. 1959a. Small tractors, ground skidding reduce tree damage in selection harvest. *Timberman* (October): 1-3.

———. 1959b. *Sugar maple and yellow birch seed dispersal from a fully stocked stand of mature northern hardwoods in the Upper Peninsula of Michigan*. Tech. Note no. 561. St. Paul, Minn.: Lake States For. Expt. Sta., U.S. Dep. Agric.

Berry, A.B. 1981. *A study in single-tree selection for tolerant hardwoods*. Inf. Rep. PI-X-8. Petawawa: Nat. For. Instit., Can. For. Serv.

Berry, F.H., and F.F. Lombard. 1978. *Basidiomycetes associated with decay of living oak trees*. Res. Pap. NE-413. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Bey, C.F. 1964. Advance oak reproduction grows fast after clearcutting. *J. For.* 62:339-40.

Bickerstaff, A., W.L. Wallace, and F. Evert. 1981. *A quantitative description of the land base and the mean annual increment*. Pt. 2 of *Growth of forests in Canada*. Inf. Rep. PI-X-1. Petawawa: Nat. For. Instit, Can. For. Serv.

Bickford, C.A., F.S. Baker, and F.G. Wilson. 1957. Stocking, normality, and measurement of stand density. *J. For.* 55:99-104.

Bjorkbom, J.C., and R.S. Walters. 1986. *Allegheny hardwood regeneration response to even-age harvesting methods*. Res. Pap. NE-581. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Blum, B.M. 1963. *Excessive exposure stimulates epicormic branching in young northern hardwoods*. Res. Note NE-9. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1975. Regeneration and uneven-aged silviculture: The state of the art. In *Proc. of Uneven-aged Silviculture and Management in the U.S. Symp. at Morgantown, W.Va.*, Gen. Tech. Rep. WO-24, 67-87. Washington: For. Serv., U.S. Dep. Agric.

Boivin, J.L. 1985. Coupes par bandes dans des peuplements de feuillées: Resultats apres 14 ans. *For. Chron.* 61:229-32.

Books, D.J., and C.H. Tubbs. 1970. *Relation of light to epicormic sprouting in sugar maple*. Res. Note NC-93. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Boothby, R.D., and J. Buongiorno. 1985. *UNEVEN: A computer model of uneven-aged forest management*. Res. Pap. R3285. Madison: Dep. For., Univ. of Wis.

Bormann, F.H., and G.E. Likens. 1979. *Pattern and process in a forested ecosystem*. New York: Springer-Verlag.

Botkin, D.B., J.F. Janak, and J.R. Wallis. 1972. Some ecological consequences of a computer model of forest growth. *J. Ecol.* 60:849-72.

Bowen, M.G. 1974. *Selected metric (SI) units and conversion factors for Canadian forestry*. Ottawa: For. Manag. Instit., Can. For. Serv.

Boyce, S.G., and R.D. Carpenter. 1968. *Provisional grade specifications for hardwood growing-stock trees*. Res. Pap. NE-97. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Brand, G. 1981. *Simulating timber management in Lake States forests*. Gen. Tech. Rep. NC-69. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Brown, D.M., G.A. McKay, and L.J. Chapman. 1974. *The climate of southern Ontario*. 2nd ed. Climatological Studies no. 5. Ottawa: Atmospheric Environ. Serv., Environ. Can.

Brown, G. 1973. Direct seeding in Ontario. In *Proc. of Direct Seeding Symp. at Timmins, Ont.*, edited by J.H. Cayford, Publ. no. 1339, 119-24. Ottawa: Can. For. Serv.

Bruce, D.S., and C.J. Heeney. 1974. *A silvicultural guide to the hard maple, yellow birch and hemlock working groups in Ontario*. Toronto: For. Manag. Br., Ont. Min. Nat. Resour.

Burger, D. 1967. Distribution and origin of parent soil materials in part of the Ottawa-Bonnechere River valleys, Ontario. *Can. J. Earth Sci.* 4:397-411.

———. 1971. Landtype pattern maps S1-71 to S11-71 — Bobcaygeon, Limerick, Smith's Falls, Haliburton, Bancroft, Calabogie, Algonquin, Golden Lake, Ft. Coulonge, Mattawa, Deep River (scale 1:125 000). Maple: For. Res. Br., Ont. Min. Nat. Resour.

Burger, D., and Z. Shidong. 1988. An introductory comparison of forest ecological conditions in northeast China and Ontario, Canada. *For. Chron.* 64:105-115.

Burkle, J.L., and S. Guttenberg. 1952. *Marking guides for oaks and yellow-poplar in the southern uplands*. Occas. Pap. no 125. New Orleans, La.: South. For. Expt. Sta., U.S. Dep. Agric.

Burns, R.M. 1983. *Silvicultural systems for the major forest types of the United States*. Agric. Handbook no. 445. Washington: For. Serv., U.S. Dep. Agric.

Burton, D.H., H.W. Anderson, and L.F. Riley. 1969. Natural regeneration of yellow birch in Canada. In *Proc. of the Birch Symp. at Durham, N.H.*, edited by E. Larson, 55-73. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Burton, D.H., and N.H. Sloane. 1958. *Progress report on prescribed burning in the hard maple-yellow birch cover type in Ontario*. For. Sect. Rep. no. 25. Toronto: Div. Res., Ont. Dep. Lands and Forests.

Calvert, R.F. 1979. Status of hardwood tree improvement. In *Proc. of Tree Improve. Symp.*, compiled by Can.-Ont. Joint For. Res. Comm. and edited by J.B. Scarratt, Publ. O-P-7, 161-66. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

Canada Soil Survey Committee. 1987. *The Canadian system of soil classification*. Compiled by the Subcommittee on Soil Classification, Res. Publ. no. 1646. Ottawa: Can. Dep. of Agric.

Carl, C.M., Jr., and H.W. Yawney. 1977. Fall versus spring sowing of sugar maple seed in a nursery. *Tree Planters' Notes* 28:24-26.

Carvell, K.L. 1967. *The response of understory oak seedlings to release after partial cutting*. Bull. no. 553. Morgantown: Agric. Expt. Sta., W.Va Univ.

———. 1971. Silvicultural aspects of intermediate cuttings. In *Proc. of Oak Symp. at Morgantown, W.Va.*, 60-64. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Carvell, K.L., C.B. Koch., and D.J. Frederick. 1973. *The relationship between certain external characteristics and internal defect in black cherry.* Bull. no. 615. Morgantown: Agric. Expt. Sta., W.Va Univ.

Cech, F.C. 1971. Tree improvement research in oak species. In *Proc. of Oak Symp. at Morgantown, W.Va.*, 55-59. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Chapman, L.J., and D.F. Putnam. 1984. *The physiography of southern Ontario.* 3rd ed. Special vol. 2. Toronto: Ont. Res. Found., Ont. Geological Survey.

Chen, C.M., D.W. Rose, and R.A. Leary. 1980. *How to formulate and solve optimal stand density over time problems for even-aged stands using dynamic programming.* Gen. Tech. Rep. NC-56. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Church, T.W., Jr. 1955. Weeding: An effective treatment for stimulating growth of northern hardwoods. *J. For.* 53:717-19.

———. 1960. Factors affecting the development and survival of sugar maple sprouts. In *Proc. of Soc. Amer. For. Conv.*, 32-35. Washington: Soc. Amer. For.

Clark, F.B., and R.F. Watt. 1971. Silvicultural methods for regenerating oaks. In *Proc. of Oak Symp. at Morgantown, W.Va.*, 37-43. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Clausen, K.E. 1973. *Genetics of yellow birch.* Res. Pap. WO-18. Washington: For. Serv., U.S. Dep. Agric.

Clausen, K.E., and R.M. Godman. 1967. *Selecting superior yellow birch trees.* Res. Pap. NC-20. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

———. 1969. *Bark characteristics indicate age and growth rate of yellow birch.* Res. Note NC-75. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Clements, J.R. 1973. Report on symposia: "Ecological impact of management practices in eastern deciduous forests" and "Synthesis of coniferous biome research, IBP, analysis of ecosystems project." 24th Annual Meeting of AIBS, Univ. of Mass., Amherst. Petawawa: Nat. For. Instit., Can. For. Serv.

Clutter, J.L., J.C. Fortson, L.V. Pienaar, G.H. Brister, and R.L. Bailey. 1983. *Timber management: A quantitative approach.* Toronto: John Wiley & Sons.

Conover, D.F., and R.A. Ralston. 1959. Results of crop tree thinning and pruning in northern hardwood saplings after 19 years. *J. For.* 57:551-57.

Cooley, J.H. 1964. The effect of selection cutting on cull in northern hardwoods. *J. For.* 62:823-24.

Cowell, D.W. 1986. *Assessment of aquatic and terrestrial acid precipitation sensitivities for Ontario.* APIOS Rep. no. 009/86. Toronto: Ont. Min. of Environ.

Crow, T.R., R.D. Jacobs, R.R. Oberg, and C.H. Tubbs. 1981. *Stocking and structure for maximum growth in sugar maple selection stands.* Res. Pap. NC-199. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Crow, T.R., and F.T. Metzger. 1987. Regeneration under selection cutting. In *Proc. of Managing North. Hardwoods Silvicultural Symp. at Syracuse*, edited by R.D. Nyland, Publ. no. 13 (ESF 87-002), 81-94. Syracuse: Coll. Environ. Sci. and Forestry, State Univ. of N.Y.

Cunningham, F.E., and R.J. Peterson. 1965. *Air-layering sugar maple*. Res. Pap. NE-42. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Currell, R.J. 1978. Strip cutting in tolerant hardwoods: A regeneration assessment. M.Sc.F. thesis, Faculty of Forestry, Univ. of Toronto.

DeBald, P.S., and J.J. Mendel. 1976. *SETS: Stand Evaluation Tools. I. An individual-tree approach to making stand evaluations*. Res. Pap. NE-336. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Deitschman, G.H., and D.E. Herrick. 1957. Logging injury in Central States upland hardwoods. *J. For.* 55:273-77.

Dixon, R.M. 1982. The use of prescribed burning in forest management by the Ministry of Natural Resources. Toronto: Ont. Min. Natural Resour.

Downs, A.A. 1946. Response to release of sugar maple, white oak and yellow poplar. *J. For.* 44:22-27.

Drinkwater, M.H. 1960. *Crown release of young sugar maple*. Tech. Note no. 89. For. Res. Div., Can. Dep. North. Affairs and Nat. Resour.

Ek, A.R., and R.A. Monserud. 1979. Performance and comparison of stand growth models based on individual tree and diameter-class growth. *Can. J. For. Res.* 9:231-44.

Ek, A.R., S.R. Shifley, and T.E. Burk, eds. 1987. Forest growth modelling and prediction. In *Proc. of IUFRO Conf. at Minneapolis. Minn.*, Publ. no. 87-12. Washington: Soc. Amer. For.

Ellis, R.C. 1971. *An examination of timber stand improvement treatments in some southern Ontario hardwood stands*. Internal Rep. O-32. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

———. 1979. Response of crop trees of sugar maple, white ash and black cherry to release and fertilization. *Can. J. For. Res.* 9:179-88.

Erdmann, G.G. 1983. Tending valuable young northern and central hardwoods in natural stands. In *Proc. of Silviculture of Established Stands in North Central Forests Tech. Conf. at Duluth, Minn.*, edited by J.C. Stier, Publ. no. 83-11, 76-95. Washington: Soc. Amer. For.

———. 1987. Methods of commercial thinning in even-aged northern hardwood stands. In *Proc. of Managing North. Hardwoods Silvicultural Symp. at Syracuse*, edited by R.D. Nyland, Publ. no. 13 (ESF 87-002), 191-210. Syracuse: Coll. Environ. Sci. and Forestry, State Univ. of N.Y.

Erdmann, G.G., and R.M. Godman. n.d. *Regenerating eastern hemlock in the Lake States*. North. Hardwood Notes no. 3.05. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Erdmann, G.G., R.M. Godman, and G.A. Mattson. 1975a. *Effects of crown release and fertilizer on small sawlog-sized yellow birch*. Res. Pap. NC-119. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Erdmann, G.G., R.M. Godman, and R.R. Oberg. 1975b. *Crown release accelerates diameter growth and crown development of yellow birch saplings*. Res. Pap. NC-117. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Erdmann, G.G., and R.R. Oberg. 1973. *Fifteen-year results from six cutting methods in second-growth northern hardwoods*. Res. Pap. NC-100. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Erdmann, G.G., and R.M. Peterson, Jr. 1972. *Crown release increases diameter growth and bole-sprouting of pole-size yellow birch*. Res. Note NC-130. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Erdmann, G.G., R.M. Peterson, Jr., and R.M. Godman. 1981. Cleaning yellow birch seedling stands to increase survival, growth, and crown development. *Can. J. For. Res.* 11:62-68.

Ernst, R.L., and W.H. Knapp. 1985. *Forest stand density and stocking: Concepts, terms and the use of stocking guides*. Gen. Tech. Rep. WO-44. Washington: For. Serv., U.S. Dep. Agric.

Expert Committee on Soil Survey. 1983. *The Canadian soil information system (CanSIS): Manual for describing soils in the field*. Rev. 1982. Compiled by the Working Group on Soil Survey Data and edited by J.H. Day. Contribution no. 82-52. Ottawa: Agric. Can. Resour. Res. Instit.

Eyre, F.H., and W.M. Zillgitt. 1953. *Partial cuttings in northern hardwoods in the Lake States*. Tech. Bull. no. 1076. Washington: For. Serv., U.S. Dep. Agric.

Farmer, R.E., Jr. 1973. Decision making for development and use of genetically improved hardwoods. *J. For.* 71:74-78.

Farmer, R.E., Jr., and K.D. Besemann. 1974. Rooting cuttings from physiologically mature black cherry. *Silvae Genet.* 23:104-5.

Ffolliott, P.F., K.N. Brooks, and D.P. Guertin. 1984. Multiple-resource modeling: Lake States' application. *North. J. Appl. For.* 1:80-84.

Fisher, J.E., and D.W. Taber. 1975. *Logging road and skid trail construction*. Rep. no. 6. Syracuse: Appl. For. Res. Instit., State Univ. of N.Y.

Foster, N.W. 1985. Neutralization of acid precipitation within a maple-birch ecosystem. *Tappi J.* 68:104-6.

Foster, N.W., and J.A. Nicolson. 1984. Acid precipitation and water quality within a tolerant hardwood stand and soil. In *Proc. of Inter. Forestry Cong. at Quebec City*, 337-42.

Fowells, H.A. comp. 1965. *Silvics of forest trees of the United States*. Agric. Handbook no. 271. Washington: For. Serv., U.S. Dep. Agric.

FPAPA. 1979. *Proper felling techniques*. Publ. Fe-101. North Bay: For. Prod. Accident Prevention Assoc.

———. 1984. *The cutting edge*. North Bay: For. Prod. Accident Prevention Assoc.

Francis, J.K., and D.L. Bivens. 1985. Yellow-poplar and black cherry grow well after underplanting and release. *Tree Planters' Notes* 36:8-9.

Gabriel, W.J., J.W. Marvin, and F.H. Taylor. 1961. *Rooting greenwood cuttings of sugar maple: Effect of clone and medium.* Sta. Pap. no. 144. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Gall, W.R., and K.A. Taft. 1973. Variation in height growth and flushing of northern red oak (*Quercus rubra* L.). In *Proc. of Twelfth South. For. Tree Improv. Conf. at Baton Rouge, La.*, 190-99. New Orleans, La.: South. For. Expt. Sta., U.S. Dep. Agric.

Gevorkiantz, S.R. 1956. Managing northern hardwoods for quality increment. *J. For.* 54:836-40.

Gingrich, S.F. 1964. Criteria for measuring stocking in forest stands. In *Proc. of Soc. Amer. For. Conf.*, 198-201. Washington: Soc. Amer. For.

———1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the central states. *For. Sci.* 13:38-53.

———. 1971. Stocking, growth and yield of oak stands. In *Proc. of Oak Symp. at Upper Darby, Pa.*, 65-73. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Godman, R.M. 1957. *Silvical characteristics of sugar maple* (Acer saccharum). Sta. Pap. no. 50. St. Paul, Minn.: Lake States For. Expt. Sta., U.S. Dep. Agric.

———. 1986. Silvicultural considerations in thinning. In *Proc. of Hardwood Thinning Opportunities in the Lake States Symp. at Escanaba, Mich.*, compiled by J.A. Sturos, Gen. Tech. Rep. NC-113, 26-30. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

———. n.d.a. *A worksheet for shelterwood marking.* North. Hardwood Notes no. 2.04. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

———. n.d.b. *Even-age versus all-age management.* North. Hardwood Notes no. 2.02. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

———. n.d.c. *Hardwood planting.* North. Hardwood Notes no. 3.07. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

———. n.d.d. *Lake States management differs from northeast.* North. Hardwood Notes no. 1.02. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

———. n.d.e. *Prescribed burning for the birches and hemlock.* North. Hardwood Notes no. 3.06. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Godman, R.M., and D.J. Books. 1971. *Influence of stand density on stem quality in pole-size northern hardwoods.* Res. Pap. NC-54. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Godman, R.M., and G.G. Erdmann. 1983. Factors in the improvement of stem quality. In *Proc. of Silviculture of Established Stands in North Central Forests Tech. Conf. at Duluth, Minn.*, edited by J.C. Stier, Publ. no. 83-11, 69-75. Washington: Soc. Amer. For.

———. n.d. *Regenerating yellow birch in the Lake States.* North. Hardwood Notes no. 3.04. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Godman, R.M., and D.A. Marquis. 1969. Thinning and pruning in young birch stands. . In *Proc. of the Birch Symp. at Durham, N.H.*, edited by E. Larson, 119-127. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Godman, R.M., and G.A. Mattson. 1980. Low temperatures optimum for field germination of northern red oak. *Tree Planters' Notes* 31:32-34.

———. n.d. *Direct seeding*. North. Hardwood Notes no. 3.08. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Godman, R.M., and C.H. Tubbs. 1973. *Establishing even-age northern hardwood regeneration by the shelterwood method: A preliminary guide*. Res. Pap. NC-99. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Gordon, A.M. 1986. Post harvesting silvicultural techniques to enhance white pine and red oak components in shallow site forests. COFRDA Project no. 33012., Univ. of Guelph.

Gottschalk, K.W. 1985. Effects of shading on growth and development of northern red oak, black oak, black cherry and red maple seedlings. I. Height, diameter and root/shoot ratio. In *Proc. of Fifth Central Hardwoods Forest Conf. at Univ. of Ill.*, edited by J.O. Dawson and K.A. Majerus, SAF Publ. no. 85-05, 189-95. Urbana-Champaign, Ill.: Dep. For., Univ. of Ill.

Gottschalk, K.W., and D.A. Marquis. 1982. Survival and growth of planted red oak and white ash as affected by residual overstory density, stock size and deer browsing. In *Proc. of Fourth Central Hardwoods Forest Conf. at Univ. of Ky.*, edited by R.N. Muller, 125-40.

Grisez, T.J. 1975. *Flowering and seed production in seven hardwood species*. Res. Pap. NE-315. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Grisez, T.J., and J.J. Mendel. 1972. *The rate of value increase for black cherry, red maple and white ash*. Res. Pap. NE-231. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Gross, H.L. 1985. *The impact of insects and diseases on the forests of Ontario*. Inf. Rep. O-X-366. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

Gunter, J.E. 1983. Analysis of silvicultural investments. In *Proc. of Silviculture of Established Stands in North Central Forests Tech. Conf. at Duluth, Minn.*, edited by J.C. Stier, Publ. no. 83-11, 45-52. Washington: Soc. Amer. For.

Haight, R.G. 1987. Evaluating the efficiency of even-aged and uneven-aged stand management. *For. Sci.* 33:116-34.

Hamilton, G.J. 1969. The dependence of volume increment of individual trees on dominance, crown dimensions and competition. *Forestry* 42 (2): 133-44.

Hannah, P.R. 1973. Phosphorus stimulates growth of yellow birch seedlings. *Tree Planters' Notes* 24:1-2, 11.

———. 1974. Crop tree thinning increases availability of soil water to small yellow birch poles. *Soil Sci. Soc. Am. Proc.* 38:672-75.

———. 1978. Growth of large yellow birch saplings following crop tree thinning. *J. For.* 76:222-23.

———. 1985. Response of yellow birch and sugar maple to release and fertilizer. *North. J. Appl. For.* 2:108-10.

———. 1988a. The shelterwood method in northeastern forest types: A literature review. *North. J. Appl. For.* 5:70-77.

———. 1988b. Vegetative propagation of yellow birch from stem cuttings. *Tree Planters' Notes* 39:37-42.

Hannah, P.R., and T.L. Turner. 1981. Growth and survival of yellow birch, sugar maple and white ash after fall planting. *Tree Planters' Notes* 32:30-32.

Hansen, G.D. 1984. *A computer simulation model of uneven-aged northern hardwood stands under the selection system*. Rep. no. 3 (ESF 84-017). Syracuse: Coll. Environ. Sci. and Forestry, State Univ. of N.Y.

Hansen, G.D., and R.D. Nyland. 1987. Effects of diameter distribution on the growth of simulated uneven-aged sugar maple stands. *Can. J. For. Res.* 17:1-8.

Hartman, R.L., and H.G. Gibson. 1970. *Techniques for the wheeled-skidder operator*. Res. Pap. NE-170. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Hatcher, R.J. 1966. Yellow birch regeneration on scarified seedbeds under small canopy openings. *For. Chron.* 42:350-58.

Heeney, C.J. 1974. Applied silviculture in the Great Lakes-St. Lawrence and Deciduous Forest Regions of Ontario. Paper presented at the Ont. Prof. Foresters Assoc. Workshop at Dorset, Ont.

Heij, W., and N.A. Leek. 1981. Impacts of wood harvesting technology on soil and vegetation. In *Proc. of Seventeenth IUFRO World Congress (Interdivisional) in Kyoto, Japan*, 21-32.

Heikurinen, J.K., and H.M. Kershaw. 1986a. Forest soils as a management framework: The data base. In *Proc. of Site Classification in Relation to Forest Management Symp.*, compiled by Can.-Ont. Joint For. Res. Comm., Publ. O-P-14, 95-103. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

———. 1986b. Forest soils as a management framework: The application. In *Proc. of Site Classification in Relation to Forest Management Symp.*, compiled by Can.-Ont. Joint For. Res. Comm., Publ. O-P-14, 104-111. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

Hendrickson, O., J.B. Robinson, and L. Chatarpaul. 1982. *The microbiology of forest soils: A literature review*. Inf. Rep. PI-X-19. Petawawa: Nat. For. Instit., Can. For. Serv.,

Hepting, G.H. 1971. *Diseases of forest and shade trees of the United States*. Agric. Handbook no. 386. Washington: For. Serv., U.S. Dep. Agric.

Hepting, G.H., K.H. Garren, and P.W. Warlick. 1940. External features correlated with top rot in Appalachian oaks. *J. For.* 38:873-76.

Hesterberg, G.A. 1957a. *Deterioration of sugar maple following logging damage*. Sta. Pap. no. 51. St. Paul, Minn.: Lake States For. Expt. Sta., U.S. Dep. Agric.

———. 1957b. *Logging damage risk classification for sugar maple*. Tech. Note no. 488. St. Paul, Minn.: Lake States For. Expt. Sta., U.S. Dep. Agric.

Hibbs, D.E., and W.R. Bentley. 1984. A growth model for red oak in New England. *Can. J. For. Res.* 14:250-54.

Higgs, B. 1981. Hardwood silviculture: A look at the pre-commercial thinning and planting programs underway at Valley Forest Products Ltd. *Pulp and Pap. Can.* 82 (7): 26-32.

Hill, J.P., and D.I. Dickmann. 1988. A comparision of three methods for naturally reproducing oaks in southern Michigan. *North. J. Appl. For.* 5:113-17.

Hills, G.A. 1959. A ready reference to the description of the land of Ontario and its productivity. Toronto: Ont. Dep. Lands and Forests.

———. 1960. The soils of the Canadian shield. *Agric. Instit. Rev.* 15 (2): 41-43.

Hills, G.A., and W.G.E. Brown. 1955. The sites of the University of Toronto Forest. Paper prepared for Eighth Annual Meeting Northeast. Forest Soils Conf., Ontario, Aug. 1-4, 1955.

Hilt, D.E. 1985a. *OAKSIM: An individual-tree growth and yield simulator for managed, even-aged upland oak stands.* Res. Pap. NE-562. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1985b. Species composition of young central hardwood stands that develop after clearcutting. In *Proc. of Fifth Central Hardwoods Forest Conf. at the Univ. of Ill.*, edited by J.O. Dawson and K.A. Majerus, SAF Publ. no. 85-05, 11-14. Urbana-Champaign, Ill.: Dep. For., Univ. of Ill.

Holcomb, C.J., and C.A. Bickford. 1952. *Growth of yellow poplar and associated species in West Virginia as a guide to selective cutting.* Sta. Pap. no. 52. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Holowacz, J. 1960. *Progess report on prescribed burning in the hard maple-yellow birch cover type in Ontario 1958-1959.* For. Sect. Rep. no. 37. Toronto: Div. Res., Ont. Dep. Lands and Forests.

Hopper, G.M., D.W. Smith, and D.J. Parrish. 1985. Germination and seedling growth of northern red oak: Effects of stratification and pericarp removal. *For. Sci.* 31:31-39.

Horton, K.W. 1964. Scarifying and screefing for regeneration. *Can. Lumberman* (January): 1-4.

Hough, A.F. 1959. Zoning for the management of black cherry on the Allegheny Plateau. *J. For.* 57:353-57.

Houston, D.R. 1981. *Stress-triggered tree disease: The diebacks and declines.* Inf. Rep. NE-41-81. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Huntzinger, H.J. 1964. *Germination, survival and first-year growth of black cherry under various seedbed and supplemental treatments.* Res. Note NE-26. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Hutnik, R.J. 1958. Converting all-aged stand tables by 1-inch diameter classes to 2-inch classes. *J. For.* 56:142-43.

Hynard, P.P. 1984. *A decision-making model for forest managers using economic considerations.* Toronto: Ont. Min. Natural Resour.

Irwin, J.R. 1972. Logging damage in partially cut hardwood stands in Parry Sound District. Parry Sound: Ont. Min. Natural Resour.

———. 1988. *Key to silvicultural prescriptions for areas of natural and scientific interest.* Cambridge: Ont. Min. Natural Resour.

Isebrands, J.G., and T.R. Crow. 1985. Techniques for rooting juvenile softwood cuttings of northern red oak. In *Proc. of Fifth Central Hardwoods Forest Conf. at the Univ. of Ill.*, edited by J.O. Dawson and K.A. Majerus, SAF Publ. no. 85-05, 11-14. Urbana-Champaign, Ill.: Dep. For., Univ. of Ill.

Jaciw, P. 1986. Hardwood thinning. Maple: Ont. Tree Improv. and For. Biomass Instit. Photocopy.

Jacobs, R.D. 1968. Growth and yield. In *Proc. of Sugar Maple Conf. at Houghton, Mich.*, 96-104. Washington: For. Serv., U.S. Dep. Agric.

———. 1974. Damage to northern hardwood reproduction during removal of shelterwood overstory. *J. For.* 72:654-56.

Johnson, D.F. 1978. Logging damage in several tolerant hardwood stands in Ontario. BScF thesis, Univ. of New Brunswick.

Johnson, G.R., Jr. 1983. Removing cull acorns from a water-willow oak acorn lot using salt solutions. *Tree Planters' Notes* 34:10-12.

Johnson, J.A. 1984a. Small-woodlot management by single-tree selection: 21 year results. *North. J. Appl. For.* 1:69-71.

Johnson, J.D. 1987. Manufacturing value added in the forest industries of Canada. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

Johnson, P.S. 1974. *Survival and growth of northern red oak seedlings following a prescribed burn.* Res. Note NC-177. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

———. 1976. Modal development of regeneration in clearcut red oak stands in the driftless area. In *Proc. of First Central Hardwoods Forest Conference at Carbondale, Ill.*, edited by J.S. Fralish, G.T. Weaver, and R.C. Schlesinger, 455-75. Washington: For. Serv., U.S. Dep. Agric.

———. 1984b. Responses of planted northern red oak to three overstory treatments. *Can. J. For. Res.* 14:536-42.

Johnson, P.S., C.D. Dale., K.R. Davidson, and J.R. Law. 1986. Planting northern red oak in the Missouri Ozarks: A prescription. *North. J. Appl. For.* 3:66-68.

Johnson, P.S., and R.M. Godman. 1983. Precommercial thinning of oak, basswood and red maple sprout clumps. In *Proc. of Silviculture of Established Stands in North Central Forests Technical Conf.*, edited by J.C. Stier, Publ. no. 83-11, 124-39. Washington: Soc. Amer. For.

Johnson, P.S., and R.D. Jacobs. 1981. *Northern red oak regeneration after preherbicided clearcutting and shelterwood removal cutting.* Res. Pap. NC-202. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Johnson, P.S., and R. Rogers. 1980. Predicting growth of individual stems within red oak sprout clumps. In *Proc. of Third Central Hardwoods Conference at Columbia, Mo.*, edited by H.E. Garrett and G.S. Cox, 420-39. Columbia: Univ. of Mo.

———. 1984. Predicting 25th-year diameters of thinned stump sprouts of northern red oak. *J. For.* 82:616-19.

———. 1985. A method for estimating the contribution of planted hardwoods to future stocking. *For. Sci.* 31:883-91.

Johnson, R.L. 1979. Adequate oak regeneration: A problem without a solution? In *Proc. of Seventh Annual Hardwood Symp. of the Hardwood Research Council at Cashiers, N.C.*, 59-65. Atlanta, Ga.: For. Serv., U.S. Dep. Agric.

Johnson, R.L., and R.M. Krinard. 1985. Regeneration of oaks by direct seeding. In *Proc. of Third Southeastern Hardwoods Symp. at Atlanta, Ga.*, 56-65. New Orleans, La.: South. For. Expt. Sta., U.S. Dep. Agric.

Jordon, J.J., and W.M. Sharp. 1967. *Seeding and planting hemlock for ruffed grouse cover.* Res. Pap. NE-83. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Kasile, J.D. 1982. Hardwood lumber, log and tree grading. In *Proc. of Soc. Amer. For. Conv. at Cincinnati, Ohio*, SAF Publ. no. 83-04, 108-109. Washington: Soc. Amer. For.

Keetch, J.J. 1944. *Sprout development on once-burned and repeatedly-burned areas in the southern Appalachians.* Tech. Note no. 59. Asheville, N.C.: Appalachian For. Expt. Sta., U.S. Dep. Agric.

Kimmins, J.P., and K.A. Scoullar. 1984. *FORCYTE-10: A user's manual.* Vancouver: Faculty of Forestry, Univ. of British Columbia.

King, W.W. 1963. Merchantable stem skidding and damage. *J. For.* 61:846-49.

Kolenosky, G.B. 1981. *A summary of black bear ecology and management.* Toronto: Wildl. Br., Ont. Min. Natural Resour.

Kriebel, H.B. 1957. *Patterns of genetic variation in sugar maple.* Res. Bull. no. 791. Wooster: Ohio Agric. Expt. Sta., U.S. Dep. Agric.

———. 1963. *Some techniques for early diagnosis of genotype in* Acer saccharum *L.* 68-70. Der Zuchter 6 Sonderheft.

Kriebel, H.B., and W.J. Gabriel. 1969. *Genetics of sugar maple.* Res. Pap. WO-7. Washington: For. Serv., U.S. Dep. Agric.

Lamson, N.I. 1983. Precommercial thinning increases diameter growth of Appalachian hardwood stump sprouts. *South. J. Appl. For.* 7:93-97.

Lamson, N.I., and R.E. McCay. 1978. How to determine whether forest fertilization pays. In *Proc. of Second Central Hardwoods Forest Conf. at West Lafayette, Ind.*, edited by P.E. Pope, 320-27. Washington: For. Serv., U.S. Dep. Agric.

Lamson, N.I., and H.C. Smith. 1978. *Response of crop tree release: Sugar maple, red oak, black cherry and yellow-poplar saplings in a 9-year-old stand.* Res. Pap. NE-354. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1987. Precommercial treatment of 15- to 40-year old northern hardwood stands. In *Proc. of Managing Northern Hardwoods Silvicultural Symp. at Syracuse*, edited by R.D. Nyland, Publ. no. 13 (ESF 87-002), 160-75. Syracuse: Coll. Environ. Sci. and Forestry, State Univ. of N.Y.

Lamson, N.I., H.C. Smith, and G.W. Miller. 1985. Logging damage using an individual-tree selection practice in Appalachian hardwood stands. *North. J. Appl. For.* 2:117-20.

Lavallée, A. 1968. Détermination de la qualité de l'érable à sucre d'après des signes apparents de carie. *For. Chron.* 44 (4): 5-10.

Lavallée, A., and M. Lortie. 1968. Relationships between external features and trunk rot in living yellow birch. *For. Chron.* 44 (2): 5-10.

Lea, R., W.C. Tierson, and A.L. Leaf. 1979. Growth responses of northern hardwoods to fertilization. *For. Sci.* 25:597-604.

Leak, W.B. 1961. *Development of second-growth northern hardwoods on Bartlett Experimental Forest: A 25-year record.* Sta. Pap. no. 155. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1963. Calculation of "q" by least squares method. *J. For.* 61:227-28.

———. 1980. *Rapid economic analysis of northern hardwood stand improvement options.* Res. Note NE-296. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Leak, W.B., and S.M. Filip. 1975. *Uneven-aged management of northern hardwoods in New England.* Res. Pap. NE-332. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1977. Thirty-eight years of group selection in New England northern hardwoods. *J. For.* 75:641-43.

Leak, W.B., and J.H. Gottsacker. 1985. New approaches to uneven-age management in New England. *North. J. Appl. For.* 2:28-31.

Leak, W.B., D.S. Solomon, and P.S. DeBold. 1987. *Silvicultural guide for northern hardwood types in the Northeast.* Rev. edition. Res. Pap. NE-603. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Leak, W.B., D.S. Solomon, and S.M. Filip. 1969. *A silvicultural guide for northern hardwoods in the Northeast.* Res. Pap. NE-143. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Leak, W.B., and C.H. Tubbs. 1983. *Percent crown cover tables for applying the shelterwood system in New England.* Res. Note NE-313. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Leak, W.B., and R.W. Wilson, Jr. 1958. *Regeneration after cutting of old-growth northern hardwoods in New Hampshire.* Sta. Pap. no. 103. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

LeDoux, C.B. 1986. *MANAGE: A computer program to estimate costs and benefits associated with eastern hardwood management.* Gen. Tech. Rep. NE-112. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Leech, R.H., and Y.T. Kim. 1970. *Methods of foliar analysis used in forest fertilization studies.* For. Sect. Rep. no. 72. Toronto: Ont. Dep. Lands and Forests.

———. 1981. Foliar analysis and DRIS as a guide to fertilizer amendments in poplar plantations. *For. Chron.* 57:17-21.

———. 1988. Studies to improve growth and sugar yield of sugar maple. Maple: Ont. Tree Improv. and For. Biomass Instit., Ont. Min. Natural Resour.

Lockard, C.R., J.A. Putnam, and R.D. Carpenter. 1963. *Grade defects in hardwood lumber and logs.* Agric. Handbook no. 244. Washington: For. Serv., U.S. Dep. Agric.

Lorimer, C.G. 1983. A test of the accuracy of shade-tolerance classifications based on physiognomic and reproductive traits. *Can. J. Bot.* 61:1595-98.

Love, D.V., A.F. Beckwith, and Z.J.R. Morawski. 1972. *Studies of land productivity for hardwoods in southern Ontario*. Rep. no. 6. Toronto: Canada Land Inventory Program, Agricultural and Rural Develop. Admin., Can. Dep. Regional Economic Expansion.

Lozano, F.C., and K.D. Huynh. 1989. Foliar diagnosis of sugar maple decline by DRIS. *Commun. in Soil Sci. Plant Anal.* 20 (17,18): 1895-914.

MacAloney, H.J., and H.G. Ewan. 1964. *Identification of hardwood insects by type of tree injury, North-Central Region*. Res. Pap. LS-11. St. Paul, Minn.: Lake States For. Expt. Sta.and North Central Region, U.S. Dep. Agric.

MacArthur, J.D., and J.W. Fraser. 1963. Low temperature germination of some eastern Canadian tree seed. *For. Chron.* 39:478-79.

MacIver, D.C. 1986. *Climatograms/soil types for Ontario*. Toronto: For. Resour. Group, Ont. Min. Natural Resour.

Mader, S.F., and R.D. Nyland. 1984. Six-year response of northern hardwoods to the selection system. *North. J. Appl. For.* 1:87-91.

Malhotra, S.S., and R.A. Blauel. 1980. *Diagnosis of air pollutant and natural stress symptoms on forest vegetation in western Canada*. Inf. Rep. NOR-X-228. Edmonton: North. For. Centre, Can. For. Serv.

Manion, P.D. 1981. *Tree disease concepts*. Englewood Cliff, N.J.: Prentice-Hall Inc.

Marden, R.M., and C.L. Stayton. 1970. *Defect indicators in sugar maple: A photographic guide*. Res. Pap. NC-37. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Marquis, D.A. 1969. *Thinning in young northern hardwoods: 5 year results*. Res. Pap. NE-139. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1973. Factors affecting financial returns from hardwood tree improvement. *J. For.* 71:79-83.

———. 1975. Application of uneven-aged silviculture and management on public and private lands. In *Proc. of Uneven-aged Silviculture and Management in the U.S. Symp. at Morgantown, W.Va.*, Gen. Tech. Rep. WO-24, 25-61. Washington: For. Serv., U.S. Dep. Agric.

———. 1979. Shelterwood cuttings in Allegheny hardwoods. *J. For.* 77:140-44.

———. 1986. SILVAH: A stand analysis, prescription and management simulator program for hardwood stands in the Alleghenies. In *Proc. of Forestry Micro Computer Software Symp. at Morgantown, W.Va.*, 1-17.

Marquis, D.A., and R. Brenneman. 1981. *The impact of deer on forest vegetation in Pennsylvania*. Gen. Tech. Rep. NE-65. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Marquis, D.A., R.L. Ernst, and S.L. Stout. 1984. *Prescribing silvicultural treatments in hardwood stands of the Alleghenies*. Gen. Tech. Rep. NE-96. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Maynard, C.A., R.P. Overton, and L.C. Johnson. 1987. The silviculturist's role in tree improvement in northern hardwoods. In *Proc. of Managing Northern Hardwoods Silvicultural Symp. at Syracuse*, edited by R.D. Nyland, Publ. no. 13 (ESF 87-002), 35-45. Syracuse: Coll. Environ. Sci. and Forestry, State Univ. of N.Y.

McCauley, O.D., and D.A. Marquis. 1972. *Investment in precommercial thinning of northern hardwoods*. Res. Pap. NE-245. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

McCauley, O.D., and G.R. Trimble, Jr. 1975. *Site quality in Appalachian hardwoods: The biological and economic response under selection silviculture*. Res. Pap. NE-312. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

McCraw, W.E. 1967. How to profit from mechanized logging. *Can. For. Industries* 87:34-38.

McEwen, J.K., D.H. Burton, and G.A. Sinclair. 1958. *A description and evaluation of cultural treatments in the tolerant hardwood stands of the Lindsay District*. For. Sect. Rep. no. 19. Toronto: Div. Res., Ont. Dep. Lands and Forests

McGauley, B.H., and C.S. Kirby. 1985. *Common pests of trees in Ontario*. Toronto: Ont. Min. Natural Resour.

McIlveen, W.D., S.T. Rutherford, and S.N. Linzon. 1986. *A historical perspective of sugar maple decline within Ontario and outside of Ontario*. Rep. ARB-141-86-Phyto. Toronto: Air Resourc. Br., Ont. Min. of Environ.

McLaughlin, D.L. 1987. Maple decline in Ontario: Situation/research status report. In *Proc. of Maplefest '87 at Grand Falls, N.B.* Toronto: Air Resour. Br., Ont. Min. of Environ.

McLean, M.M. 1970. Quality of hard maple logs in Algonquin Park. Toronto: For. Res. Br., Ont. Dep. Lands and Forests. Photocopy.

———. 1976. Tree marking objectives and training tree markers. Dorset: For. Res. Centre, Ont. Min. Natural Resour. Photocopy.

———. 1987a. Stand growth after thinning 61-80 year age-class in tolerant hardwoods. Maple: Ont. Tree Improv. and For. Biomass Instit., Ont. Min. Natural Resour. Photocopy.

———. 1987b. Tolerant hardwood thinning studies: Algonquin Park. Maple: Ont. Tree Improv. and For. Biomass Instit., Ont. Min. Natural Resour. Photocopy.

———. 1987c. Selection cutting in tolerant hardwoods: Algonquin Park. Maple: Ont. Tree Improv. and For. Biomass Instit., Ont. Min. Natural Resour. Photocopy.

Mendel, J.J., T.J. Grisez, and G.R. Trimble, Jr. 1973. *The rate of value increase for sugar maple*. Res. Pap. NE-250. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Mendel, J.J., and G.R. Trimble, Jr. 1969. *The rate of value increase for yellow poplar and beech*. Res. Pap. NE-140. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Metzger, F.T. 1980. *Strip clearcutting to regenerate northern hardwoods*. Res. Pap. NC-186. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Meyer, G., J.H. Ohman, and R. Oettel. 1966. Skidding hardwoods: Articulated rubber-tired skidders versus crawler tractors. *J. For.* 64:191-96.

Meyer, H.A. 1952. Structure, growth and drain in balanced, uneven-aged forests. *J. For.* 50:85-92.

Miller, R., and M. Woods. 1989. *MAPLE I: A sugar maple growth model*. Sault Ste. Marie: For. Manag. Br., Ont. Min. Natural Resour.

Minckler, L.S., and S.F. Gingrich. 1970. *Relation of crown width to tree diameter in some upland hardwood stands of southern Illinois*. Res. Note NC-99. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Mitchell, K.J. 1988. SYLVER: Modelling the impact of silviculture on yield, lumber value, and economic return. *For. Chron.* 64:127-31.

Mize, C.W., and R.V. Lea. 1977. Vigor and risk classifications for northern hardwoods. *North. Logger and Timber Processor* 26 (5): 22-23, 32-33.

Morawski, Z.J.R. 1971. *Hardwood survey in southern Ontario: Quality assessment interim report.* Toronto: Div. For., Ont. Min. Natural Resour.

Morawski, Z.J.R., J.T. Basham, and K.B. Turner. 1958. *Cull studies: A survey of a pathological condition in the forests of Ontario*. Rep. no. 25. Toronto: For. Resources Inventory, Ont. Dep. Lands and Forests.

Morgenstern, E.K. 1979. Genetics of deciduous species and spruces, Petawawa, 1977-1978. In *Proc. of Seventeenth Canadian Tree Improvement Association Meeting, Part 1, at Gander, Nfld.*, edited by C.W. Yeatman, 151-55. Ottawa: Can. For. Serv.

Morriss, D.J. 1968. Even-aged management. In *Proc. of Sugar Maple Conf. at Houghton, Mich.*, 146-51. Washington: For. Serv., U.S. Dep. Agric.

Morsink, W.A.G., and E. Jorgensen. 1974. *Propagation and selection of sugar maple (*Acer saccharum *Marsh.) in Ontario*. Toronto: Ont. Min. Natural Resour.

Moser, J.W., Jr. 1980. Historical chapters in the development of modern forest growth and yield theory. In *Proc. of Forecasting Forest Stand Dynamics Workshop at Thunder Bay, Ont.*, edited by K.M. Brown and F.R. Clarke, 42-61. Thunder Bay, Ont.: Lakehead Univ.

Moser, J.W., Jr., C.H. Tubbs, and R.D. Jacobs. 1979. Evaluation of a growth projection system for uneven-aged northern hardwoods. *J. For.* 77:421-23.

Mroz, G.D., and S.G. Shetron. 1983. Fertilization in Lake States northern hardwoods management: An overview. In *Proc. of Silviculture of Established Stands in North Central Forests Tech. Conf. at Duluth, Minn.*, edited by J.C. Stier, Publ. no. 83-11, 172-79. Washington: Soc. Amer. For.

Murphy, R.J.K. n.d.a. Crop tree pruning for better quality timber in Ontario. Toronto: Timber Br., Ont. Dep. Lands and Forests.

———. n.d.b. Upland tolerant hardwood management. Toronto: Timber Br., Ont. Dep. Lands and Forests.

Myren, D.T., and E.B. Dorworth. 1986. *Names and authors used for fungi at the Great Lakes Forestry Centre*. Inf. Rep. O-X-376. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

Nyland, R.D., ed. 1972. *A perspective on clearcutting in a changing world*. Res. Rep. no. 4. Syracuse: Appl. For. Res. Instit., State Univ. of N.Y.

———. 1987. Selection system and its application to uneven-aged northern hardwoods. In *Proc. of Managing Northern Hardwoods Silvicultural Symp. at Syracuse*, edited by R.D. Nyland, Publ. no. 13 (ESF 87-002), 49-80. Syracuse: Coll. Environ. Sci. and Forestry, State Univ. of N.Y.

Nyland, R.D., L.P. Abrahamson, and K.B. Adams. 1983. Use of prescribed fire for regenerating red and white oak in New York. In *Proc. of Soc. Amer. For. Conv.*, 163-67. Washington: Soc. Amer. For.

Nyland, R.D., P.J. Craul, D.F. Behrend, H.E. Echelberger, W.J. Gabriel, R.L. Nissen, Jr., R. Uebler, and J. Zarnetske. 1976. *Logging and its effects in northern hardwoods*. Res. Rep. no. 31. Syracuse: Appl. For. Res. Instit., State Univ. of N.Y.

Nyland, R.D., and W.J. Gabriel. 1971. *Logging damage to partially cut hardwood stands in New York State*. Res. Rep. no. 5. Syracuse: Appl. For. Res. Instit., State Univ. of N.Y.

Nyland, R.D., and D.A. Marquis. 1978. Appropriate silvicultural systems for northern hardwoods. In *Proc. of Joint Conv. of Soc. Amer. For. and the Can. Instit. of For.*, 334-38. Washington: Soc. Amer. For.

Ohman, J.H. 1970. Value loss from skidding wounds in sugar maple and yellow birch. *J. For.* 68:226-30.

OIP. 1985. *Field manual for describing soils*. 3rd ed. Publ. no. 85-3. Guelph: Ont. Instit. of Pedology and Univ. of Guelph Land Resour. Res. Studies

Olson, J.T., A.L. Lundgren, and D. Rose. 1978. *Equations for estimating stand establishment, release and thinning costs in the Lake States*. Res. Pap. NC-163. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

OMAF. 1988. *Guide to chemical weed control.* Publ. no. 75. Toronto: Ont. Min. Agric. and Food.

OMNR. 1973. *Management of tolerant hardwoods in Algonquin Provincial Park*. Toronto: For. Manag. Br., Ont. Min. Natural Resour.

———. 1976. *Reptiles and amphibians of Algonquin Provincial Park*. Toronto: Wildl. Br., Ont. Min. Natural Resour.

———. 1977. *The planting of hardwood trees and shrubs*. Toronto: For. Manag. Br., Ont. Min. Natural Resour.

———. 1979. *Vegetation management for wildlife in Ontario*. Toronto: Wildl. Br., Ont. Min. Natural Resour.

———. 1983. *Management of tolerant hardwoods in Algonquin Provincial Park*. Toronto: For. Resour. Br., Ont. Min. Natural Resour.

——— 1984a. Habitat management guidelines for warblers in Ontario's northern coniferous forest, mixed forest or southern hardwood forests. Toronto: Wildl. Br., Ont. Min. Natural Resour.

———. 1984b. Habitat management guidelines for cavity nesting birds in Ontario. Toronto: Wildl. Br., Ont. Min. Natural Resour.

———. 1984c. Habitat management guidelines for Ontario's forest nesting accipiters, buteos and eagles. Toronto: Wildl. Br., Ont. Min. Natural Resour.

———. 1986a. *Guidelines for providing furbearer habitat in timber management*. Toronto: Wildl. Br., Ont. Min. Natural Resour.

———. 1986b. *Guidelines for tree seed crop forecasting and collecting*. Toronto: For. Resour. Br., Ont. Min. Natural Resour.

———. 1986c. *Ontario forest industry statistical reports for 1985*. Toronto: Timber Sales Br., Ont. Min. Natural Resour.

———. 1986d. *The forest resources of Ontario 1986*. Toronto: For. Resour. Br., Ont. Min. Natural Resour.

———. 1986e. *The logger's pocketbook*. Toronto: Ont. Min. Natural Resour.

———. 1986f. *Timber management planning manual for Crown lands in Ontario*. Toronto: Ont. Min. Natural Resour.

———. 1986g. The forest management challenge. Toronto: For. Resour. Group, Ont. Min. Natural Resour.

———. 1987a. *Class environmental assessment for timber management on Crown lands in Ontario*. Toronto: Ont. Min. Natural Resour.

———. 1987b. *Implementation strategy: Areas of natural and scientific interest*. Toronto: Ont. Min. Natural Resour.

———. 1987c. *Prescribed burn planning manual for Crown lands in Ontario*. Toronto: For. Resour. Group, Ont. Min. Natural Resour.

———. 1987d. *Tree improvement master plan for Ontario*. Toronto: Ont. Min. Natural Resour.

———. 1987e. *Statistics 1987*. Toronto: For. Resour. Group, Ont. Min. Natural Resour.

———. 1987f. *Timber management guidelines for providing white-tailed deer habitat*. Toronto: Wildl. Br., Ont. Min. Natural Resour.

———. 1987g. *Timber management guidelines for providing moose habitat*. Toronto: Wildl. Br., Ont. Min. Natural Resour.

———. 1987h. *Timber management guidelines for the protection of fish habitat*. Toronto: Fisheries Br., Ont. Min. Natural Resour.

———. 1987i. *Timber management guidelines for the protection of tourism values*. Toronto: Ont. Min. Natural Resour.

———. 1988. *Environmental guidelines for the construction of access roads*. Toronto: Ont. Min. Natural Resour.

Ondro, W.J., and D.V. Love. 1979. Growth response of northern hardwoods to partial cutting in southern Ontario. *For. Chron.* 55:13-16.

Ostrander, M.D. 1965. *A guide to hardwood log grading*. Rev. ed. Upper Darby, Pa.: Northeastern For. Expt. Sta., U.S. Dep. Agric.

Payandeh, B. 1973. *Plonski's yield tables formulated*. Publ. no. 1318. Ottawa: Can. For. Serv.

Perala, D.A. 1974. *Growth and survival of northern hardwood sprouts after burning*. Res. Note NC-176. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Petoskey, M.L. 1982. Controversies surrounding the management of America's hardwood forests. In

Proc. of Soc. Amer. For. Conv. at Cincinnati, Ohio, Publ. no. 83-04, 96-100. Washington: Soc. Amer. For.

Petro, F.J. 1962. *How to evaluate the quality of hardwood logs for factory lumber*. Tech. Note no. 34. Ottawa: For. Products Res. Br., Can. Dep. Forestry.

———. 1965. Why improved sawlog bucking is profitable. *North. Logger* 14:14-15, 36-39.

———. 1971. *Felling and bucking hardwoods: How to improve your profits*. Publ. no. 1291. Ottawa: Can. Dep. Fish. and For., Can. For. Serv.

Pierpoint, G. 1986. An orientation to site classification in Ontario. In *Proc. of Site Classification in Relation to Forest Management Symp.*, compiled by Can.-Ont. Joint For. Res. Comm., Publ. O-P-14, 24-28. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

Pierpoint, G., and P. Uhlig. 1985. *Catalogue of land resource surveys in Ontario of major value in forest management*. Toronto: Ont. Min. Natural Resour.

Pitcher, J.A. 1982. Phenotype selection and half-sib family performance in black cherry. *For. Sci.* 28:251-56.

Place, I.C.M. 1974. The effect of logging operations on forest management. In *Proc. of Tenth Commonwealth Conf. at Oxford, England*, 1-26. Ottawa: Can. For. Serv.

Plonski, W.L. 1960. *Normal yield tables for black spruce, jack pine, white birch, tolerant hardwoods, white pine and red pine*. Toronto: Ont. Dep. Lands and Forests.

———. 1981. *Normal yield tables (metric) for major forest species of Ontario*. Toronto: For. Resour. Group, Ont. Min. Natural Resour.

Powell, D.S., and E.H. Tryon. 1979. Sprouting ability of advance growth in undisturbed hardwood stands. *Can. J. For. Res.* 9:116-20.

Province of Ontario. 1980. *Pesticides Act*. Revised statutes of Ontario, ch. 376.

———. 1985. *Occupational health and safety act and regulations for industrial establishments*. Revised statutes of Ontario, ch. 321.

Randall, R.M., and R.W. Sassaman. 1979. *Identifying and evaluating environmental impacts associated with timber harvest scheduling policies*. Gen. Tech. Rep. PNW-81. Corvallis, Oreg.: Pac. North West For. Expt. Sta., U.S. Dep. Agric.

Rast, E.D. 1982. *Photographic guide of selected external defect indicators in northern red oak*. Res. Pap. NE-511. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Raymond, F.L., and M.M. McLean. 1984. Simulation of growth and yield of hard maple. Toronto: Timber Sales Br., Ont. Min. Natural Resour.

———. 1987. Simulation of growth and yield of hard maple (metric). Toronto: Timber Sales Br., Ont. Min. Natural Resour.

Rennolls, K., and P. Blackwell. 1986. *An integrated forest process model: Its calibration and predictive performance*. Paper no. 148. Edinburgh, Scotland: Res. and Devel., Forestry Commission (U.K.).

Roach, B.A. 1974. *Selection cutting and group selection*. Rep. no. 5. Syracuse: Appl. For. Res. Instit., State Univ. of N.Y.

———. 1977. *A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings*. Res. Pap. NE-373. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Roach, B.A., and S.F. Gingrich. 1968. *Even-aged silviculture for upland central hardwoods*. Agric. Handbook no. 355. Washington: For. Serv., U.S. Dep. Agric.

Roberge, M.R. 1977. Influence of cutting methods on natural and artificial regeneration of yellow birch in Quebec northern hardwoods. *Can. J. For. Res.* 7:175-82.

———. 1987. Managing northern hardwoods by clearcutting 30 m wide strips: 10-year results. *For. Chron.* 63:169-73.

Rogers, R. 1980. *Evaluating stocking in upland hardwood forests using metric measurements*. Res. Pap. NC-187. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Rogers, R., and P.S. Johnson. 1982. Is "COPPICE" a good predictor of red oak sprout growth? In *Proc. of Fourth Central Hardwoods Forest Conf. at Univ. of Ky.*, edited by R.N. Muller, 185-92.

———. 1985. Rule thinning: A field method for meeting stocking goals in oak stands. In *Proc. of Fifth Central Hardwoods Forest Conf. at Univ. of Ill.*, edited by J.O. Dawson and K.A. Majerus, SAF Publ. no. 85-05, 106-10. Urbana-Champaign, Ill.: Dep. For., Univ. of Ill.

Roise, J.P. 1986. An approach for optimizing residual diameter class distributions when thinning even-aged stands. *For. Sci.* 32:871-81.

Roth, E.R. 1956. Decay following thinning of sprout oak clumps. *J. For.* 54:26-30.

Rowe, J.S. 1972. *Forest regions of Canada*. Publ. no. 1300. Ottawa: Can. For. Serv.

Rudolf, P.O. 1956. *Guide for selecting superior forest trees and stands in the Lake States*. Sta. Pap. no. 40. St. Paul, Minn.: Lake States For. Expt. Sta., U.S. Dep. Agric.

Russell, T.E. 1971. Seeding and planting upland oaks. In *Proc. of Oak Symp. at Morgantown, W.Va.*, 49-54. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Safford, L.O. 1973. *Fertilization increases diameter growth of birch-beech-maple trees in New Hampshire*. Res. Note NE-182. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Sajdak, R.L. 1967. Variation in bark characters and wood specific gravity in sugar maple. In *Eighth Lake States Tree Improv. Conf.*, Res. Pap. NC-23, 10-14. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Sampson, T.L. 1983. A stocking guide for northern red oak in New England. MS thesis, Univ. of New Hampshire.

Sander, I.L. 1977. *Manager's handbook for oaks in the North Central States*. Gen. Tech. Rep. NC-37. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Sander, I.L., P.S. Johnson, and R. Rogers. 1984. *Evaluating oak advance reproduction in the Missouri Ozarks*. Res. Pap. NC-251. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Schlaegel, B.E. 1978. Growth and yield of natural hardwood stands: Concepts, practices and problems. In *Proc. of Second Symp. on Southeastern Hardwoods*, 120-29.

Scholz, H.F., and F.B. Trenk. 1959. Timber yields, wood increment and composition of regeneration in a managed hardwood forest on morainal soils. *Wisconsin Acad. Sci. Arts Letters* 48:11-29.

Shifley, S.R. 1982. A preliminary comparison of three tree growth models for Central States species. In *Proc. of Fourth Central Hardwoods Forest Conf. at Univ. of Ky.*, edited by R.N. Muller, 169-84.

———. 1987. *A generalized system of models forecasting Central States tree growth.* Res. Pap. NC-279. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Shigo, A.L. 1965. Decays and discolorations in northern hardwoods in the northeastern United States: A consideration of micro-organisms and external signs. In *Proc. of IUFRO Conf.*, Sec. 41, 1-17.

———. 1983. *Tree defects: A photo guide.* Gen. Tech. Rep. NE-82. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1984a. How to assess the defect status of a stand. *North. J. Appl. For.* 1:41-49.

———. 1984b. Tree survival after injury and infection. In *Proc. of Eighth North American Forest Biol. Workshop at Logan, Utah*, edited by R.M. Lunner, 11-24. Logan: Utah State Univ.

Shigo, A.L., and E.V. Larson. 1969. *A photo guide to the patterns of discoloration and decay in living northern hardwood trees.* Res. Pap. NE-127. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Silverborg, S.B. 1954. *Northern hardwoods cull manual.* Bull. no. 31. Syracuse: Coll. Environ. Sci. and Forestry, State Univ. N.Y.

Sinclair, G.A. 1962. *Progress report of prescribed burning in hardwood stands in Ontario.* For. Sect. Rep. no. 45. Toronto: Div. Res., Ont. Dep. Lands and Forests.

Skelly, J.M., D.D. David, W. Merrill, E.A. Cameron, H.D. Brown, D.B. Drummond, and L.S. Dochinger, eds. 1987. *Diagnosing injury to eastern forest trees.* Atlanta: National Acid Precipitation Assessment Program, For. Pest Manag., U.S. Dep. Agric.

Skilling, D.D. 1957. *Is the epicormic branching associated with hardwood pruning wounds influenced by tree crown class?* Tech. Note no. 510. St. Paul, Minn.: Lake States For. Expt. Sta., U.S. Dep. Agric.

———. 1959a. Pruning hardwoods improves quality and shows little evidence of fostering decay. *Timberman* (May): 1-3.

———. 1959b. Response of yellow birch to artificial pruning. *J. For.* 57:429-32.

Smalley, F.E. 1975. Management of northern hardwood: A possible new approach. *North. Logger and Timber Processor* 24 (5): 10, 29-30.

Smith, C.R. 1981 (with 1987 updates). *Silvicultural equipment reference catalogue for southern Ontario.* Toronto: For. Resour. Br., Ont. Min. Natural Resour.

———. 1987. Review of current uses and trends in mechanized site preparation technology applicable to Ontario conditions. In *Primeval Improvement: The New Forestry Age* in *Proc. of Can.-Ont. Joint For. Res. Comm. Symp.*, Pub. O-P-15, 31-39. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

Smith, D.M. 1962. *The practice of silviculture*. 7th edition. New York: John Wiley & Sons.

Smith, G.E. 1960. Timber management controls for eastern hardwood forests. In *Proc. of Soc. Amer. For. Conv.*, 126-31. Washington: Soc. Amer. For.

Smith, H.C. 1966. *Epicormic branching on eight species of Appalachian hardwoods*. Res. Note NE-53. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1983. *Growth of Appalachian hardwoods kept free to grow from 2 to 12 years after clearcutting*. Res. Pap. NE-528. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Smith, H.C., and N.I. Lamson. 1982. *Number of residual trees: A guide for selection cutting*. Gen. Tech. Rep. NE-80. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Smith, H.W., Jr. 1954a. Tree grades as a silvicultural tool in the management of Cumberland Plateau hardwoods. In *Proc. of Soc. Am. For. Conv.*, edited by A.B. Meyer, 66-70. Washington: Soc. Amer. For.

Smith, J.H.G. 1954b. The economics of pruning. *For. Chron.* 30:197-214.

Solomon, D.S., and B.M. Blum. 1967. *Stump sprouting of four northern hardwoods*. Res. Pap. NE-59. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Solomon, D.S., R.A. Hosmer, and H.T. Hayslett, Jr. 1987. *FIBER HANDBOOK: A growth model for spruce-fir, and northern hardwood forest types*. Res. Pap. NE-602. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Solomon, D.S., and W.B. Leak. 1969. Stocking, growth and yield of birch stands. In *Proc. of Birch Symp. at Durham, N.H*, edited by E. Larson, 106-18. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1986. *Simulated yields for managed northern hardwood stands*. Res. Pap. NE-578. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Sonderman, D.L. 1979. *Guide to the measurement of tree characteristics important to the quality classification system for young hardwood trees*. Tech. Rep. NE-54. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Sonderman, D.L., and R.L. Brisbin. 1978. *A quality classification system for young hardwood trees: The first step in predicting future products*. Res. Pap. NE-419. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Stayton, C.L., and R.M. Marden. 1970. *Is cull overestimated in northern hardwood stands?* Res. Note NC-97. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Stayton, C.L., R.M. Marden, and R.G. Buchman. 1970. Exterior defect indicators and their associated interior defect in sugar maple. *For. Prod. J.* 20:55-58.

Stayton, C.L., R.M. Marden, and G.L. Gammon. 1971. *Predicting lumber grade yields for standing hardwood trees*. Res. Pap. NC-50. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Stewart, R.E. 1978. Site preparation. In *Regenerating Oregon's Forests*, edited by B.D. Cleary, R.D. Greaves, R.K. Hermann, 100-129. Corvallis: Sch. of Forestry, Oregon State Univ.

Stoeckeler, J.H., and C.F. Arbogast. 1947. Thinning and pruning young second-growth hardwoods in northeastern Wisconsin. In *Proc. of Soc. Amer. For. Conv.*, edited by H.L. Shirley, 328-46. Washington: Soc. Amer. For.

Stokes, R. 1983. Logging damage in tolerant hardwoods. Bracebridge: Ont. Min. Natural Resour.

Stone, D.M. 1980. Fertilization of a pole-sized maple stand: 10-year results. *Can. J. For. Res.* 10:158-63.

———. 1986. Effect of thinning and nitrogen fertilization on diameter growth of pole-size sugar maple. *Can. J. For. Res.* 16:1245-49.

Stone, D.M., and D.J. Frederick. 1979. Cambial necrosis of sugar maple associated with tree marking paint. *J. For.* 77:578-80.

Stout, S.L. 1987. Planning the right residual: relative density, stand structure and species composition. In *Proc. of Managing Northern Hardwoods Silvicultural Symp. at Syracuse*, edited by R.D. Nyland, Publ. no. 13 (ESF 87-002), 176-90. Syracuse: Coll. Environ. Sci. and Forestry, State Univ. of N.Y.

Strickland, D., and R.J. Rutter. 1983. *Mammals of Algonquin Provincial Park*. Toronto: Wildl. Br., Ont. Min. Natural Resour.

Strickland, D., R. Tozer, and R.J. Rutter. 1980. *Birds of Algonquin Park*. Toronto: Wildl. Br., Ont. Min. Natural Resour.

Stroempl, G. 1983. *Thinning clumps of northern hardwood stump sprouts to produce high quality timber*. For. Res. Inf. Pap. no. 104. Maple: Ont. Tree Improv. and For. Biomass Instit., Ont. Min. Natural Resour.

———. 1986. Red oak regeneration by planting and sowing after a prescribed burn in a shelterwood stand. Maple: Ont. Tree Improv. and For. Biomass Instit., Ont. Min. Natural Resour.

———. 1987a. *Growth and quality of red oak planted in a jack pine plantation*. For. Res. Note no. 44. Maple: Ont. Tree Improv. and For. Biomass Instit., Ont. Min. Natural Resour.

———. 1987b. *Growth and quality of red oak planted in red pine plantation openings*. For. Res. Rep. no. 117. Maple: Ont. Tree Improv. and For. Biomass Instit., Ont. Min. Natural Resour.

Sutherland, B.J. 1986. *Standard assessment procedures for evaluating silvicultural equipment: A handbook*. Sault Ste. Marie: Great Lakes For. Res. Centre., Can. For. Serv.

Sutton, R.F. 1985. *Vegetation management in Canadian forestry*. Inf. Rep. O-X-369. Ottawa: Can. For. Serv.

Swan, H.S.D. 1969. *Fertilizers: Their role in reforestation*. Woodland Pap. no. 9. Pointe Claire, Que.: Pulp and Pap. Res. Instit. of Canada.

Sykes, J.M. 1964. *Report on the interim results of prescribed spring burning in a poor quality hardwood stand*. For. Sect. Rep. no. 49. Toronto: Div. Res., Ont. Dep. Lands and Forests.

Taylor, E.P. 1981. *The relationship between the soils and forest tree species of southern Ontario (Site region 6E and 7E): A literature review*. Guelph: Ont. Instit. of Pedology.

———. 1986. Soil interpretation and training program for the Central and Southwestern regions 1980-1985. In *Proc. of Site Classification in Relation to Forest Management Symp.*, compiled by Can.-Ont.

Joint For. Res. Comm., Publ. O-P-14, 135-42. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

Taylor, E.P., and P.K. Jones. 1986. *Soil interpretation and training for forestry 1981-1985 in the Central and Southwestern Regions, Site region 6E and 7E*. Guelph: Ont. Instit. of Pedology.

Teclaw, R.M., and J.G. Isebrands. 1986. Collection procedures affect germination of northern red oak (*Quercus rubra* L.) acorns. *Tree Planters' Notes* 37:8-12.

Temple, T.J., R.D. Nyland, and P.J. Craul. 1987. Growth of uneven-aged stands in New York's Adirondack Mountains. *North. J. Appl. For.* 4:136-39.

Teskey, S.B. 1986. Economics of site evaluation: Northeastern Region economic prime sites model. In *Proc. of Site Classification in Relation to Forest Management Symp.*, compiled by Can.-Ont. Joint For. Res. Comm., Publ. O-P-14, 113-17. Sault Ste. Marie: Great Lakes For. Res. Centre, Can. For. Serv.

Thomas, J.W. 1979. *Wildlife habitat in managed forests: The Blue Mountains of Oregon and Washington*. Agric. Handbook no. 553. Washington: For. Serv., U.S. Dep. Agric.

Treidl, R.A. 1978. *Handbook on agricultural and forest meteorology*. Ottawa: Can. For. Serv.

Trimble, G.R., Jr. 1960. Relative diameter growth rates of five upland oaks in West Virginia. *J. For.* 58:111-15.

———. 1963. *Cull development under all-aged management of hardwood stands*. Res. Pap. NE-10. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1965a. Reducing the proportion of cull material in hardwood stands. *North. Logger*, (August).

———. 1965b. *Species composition changes under individual tree selection cutting in cove hardwoods*. Res. Note NE-30. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1969. *Diameter growth of individual hardwood trees: The effect of certain tree and environmental factors on the growth of several species*. Res. Pap. NE-145. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1973. *The regeneration of Central Appalachian hardwoods with emphasis on the effects of site quality and harvesting practice*. Res. Pap. NE-282. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1974. *Response to crop tree release by 7-year-old stems of red maple stump sprouts and northern red oak advance reproduction*. Res. Pap. NE-303. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

———. 1975. *Summaries of some silvical characteristics of several Appalachian hardwood trees*. Gen. Tech. Rep. NE-16. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Trimble, G.R., Jr., and G. Hart. 1961. *An appraisal of early reproduction after cutting in northern Appalachian hardwood stands*. Sta. Pap. no. 162. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Trimble, G.R., Jr., and J.J. Mendel. 1969. *The rate of value increase for northern red oak, white oak, and chestnut oak*. Res. Pap. NE-129. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Trimble, G.R., Jr., J.J. Mendel, and R.A. Kennell. 1974. *A procedure for selection marking in hardwoods combining silvicultural considerations with economic guidelines*. Res. Pap. NE-292. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Trimble, G.R., Jr., and D.W. Seegrist. 1973. *Epicormic branching on hardwood trees bordering forest openings*. Res. Pap. NE-261. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Trimble, G.R., Jr., and H.C. Smith. 1963. *What happens to living cull trees left after heavy cutting in mixed hardwood stands?* Res. Note NE-12. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Trimble, G.R., Jr., and G.W. Wendel. 1963. *Cost of marking hardwood sawtimber in West Virginia*. Res. Note NE-15. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Tubbs, C.H. 1965. *Influence of temperature and early spring conditions on sugar maple and yellow birch germination in Upper Michigan*. Res. Note LS-72. St. Paul, Minn.: Lake States For. Expt. Sta., U.S. Dep. Agric.

———. 1968. It depends. In *Proc. of Sugar Maple Conf. at Houghton, Mich.*, 152-53. Washington: For. Serv., U.S. Dep. Agric.

———. 1977a. *Natural regeneration of northern hardwoods in the northern Great Lakes region*. Res. Pap. NC-150. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

———. 1977b. *Manager's handbook for northern hardwoods in the North Central States*. Gen. Tech. Rep. NC-39. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Tubbs, C.H., R.D. Jacobs, and D. Cutler. 1983. Northern hardwoods. In *Silvicultural Systems for the Major Forest Types of the United States*. Agric. Handbook no. 44, 121-27. Washington: For. Serv., U.S. Dep. Agric.

Tubbs, C.H., and R.R. Oberg. 1978. *How to calculate size-class distribution for all-aged forests*. St. Paul, Minn.: North Central For. Expt. Sta., U.S. Dep. Agric.

Von Althen, F.W. 1974. *Methods for the successful establishment of black cherry plantations in southern Ontario*. Inf. Rep. O-X-205. Ottawa: Can. For. Serv.

———. 1979a. *Planting and tending recommendations for red oak*. Sault Ste. Marie: Great Lakes For. Res. Centre., Can. For. Serv.

———. 1979b. *Planting and tending recommendations for white ash*. Sault Ste. Marie: Great Lakes For. Res. Centre., Can. For. Serv.

———. n.d. *A guide to hardwood planting on abandoned farmland in southern Ontario*. Sault Ste. Marie: Great Lakes For. Res. Centre., Can. For. Serv.

Von Althen, F.W., and D.P. Webb. 1980. Planting sugar maple on abandoned farmland in southern Ontario. In *Proc. of Third Central Hardwoods Forest Conf. at Univ. of Mo.*, edited by H.E. Garrett and G.S. Cox, 354-73. Columbia: Univ. of Mo.

Waldron, R.M. 1973. Direct seeding in Canada: 1900-1972. In *Proc. of Direct Seeding Symp. at Timmins, Ont.*, edited by J.H. Cayford, Publ. no. 1339, 11-27. Ottawa: Can. For. Serv.

Walsh, M. 1980. Logging damage survey: Livingstone Township. Bracebridge: Ont. Min. Natural Resour.

Ward, W.W. 1964. Live crown ratio and stand density in young, even-aged red oak stands. *For. Sci.* 10:56-65.

Wearn, V.H., E.A. Springer, and A. Lesage. 1982. *Forest manager's photo guide to prescribed burn planning*. Kapuskasing: Ont. Min. Natural Resour.

Wearstler, K.A., Jr., and B.V. Barnes. 1977. Genetic diversity of yellow birch seedlings in Michigan. *Can. J. Bot.* 55:2778-88.

Webb, D.P., D.F. Behrend, and S. Boonervang. 1977. Effects of logging on songbird populations in a northern hardwood forest. *Wildl. Monogr.* 55:1-35.

Weitzman, S., and G.R. Trimble, Jr. 1957. *Some natural factors that govern the management of oaks*. Sta. Pap. no. 88. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Wendel, G.W. 1975. *Stump sprout growth and quality of several Appalachian hardwood species after clearcutting*. Res. Pap. NE-329. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Wendel, G.W., and N.I. Lamson. 1987. *Effects of herbicide release on the growth of 8- to 12-year-old hardwood crop trees*. Res. Pap. NE-598. Upper Darby, Pa.: Northeast. For. Expt. Sta., U.S. Dep. Agric.

Williams, J.R.M. 1965. A study of potential productivity in Ontario. Paper presented at the Northeast. For. Soils Conf. at Simcoe, Ont.

Wilusz, W., and M. Giertych. 1974. Effects of classical silviculture on the genetic quality of the progeny. *Silvae Genet.* 23, 4:127-30.

Wray, D.O., J.S. Miller, P. Murray, J.O. Smith, W.M. Stiell, and A. Vietinghof. 1985. *Report of the Great Lakes-St. Lawrence Forest Management Committee on tolerant hardwood in Ontario (status of management)*. Toronto: Ont. Prof. Foresters Assn.

Wright, J.W. 1944. Genotypic variation in white ash. *J. For.* 42:489-95.

Zillgitt, W.M. 1949. *Basal area in merchantable trees as an expression of stocking in northern hardwoods*. Tech. Note no. 324. St. Paul, Minn.: Lake States For. Expt. Sta., U.S. Dep. Agric.

Zillgitt, W.M., and S.R. Gevorkiantz. 1948. Estimating cull in northern hardwoods with special reference to sugar maple. *J. For.* 46:588-94.

Zobel, B., and J. Talbert. 1984. *Applied forest tree improvement*. New York: John Wiley & Sons.

Zoltai, S.N. 1986. Ecoclimatic regions of Canada. Maple: Ont. Tree Improve. and For. Biomass Instit., Ont. Min. Natural Resour. Photocopy.

APPENDIX: Abbreviations for the Tree Species in the Guide

Species Name	Abbreviation	Other References
Ash white	Aw	
Ash black	Ab	
Ash blue		blue Ash
Ash red		r Ash
Ash green		g Ash
Basswood	Bd	
Beech american	Be	
Birch white	Bw	
Birch yellow	By	
Butternut	Bn	
Cedar white	Cw	
Cherry black	Cb	
Elm american	Ea	
Elm slippery		s Elm
Elm rock		r Elm
Fir balsam	Bf	
Hemlock eastern	He	
Hickory shag bark	Hs	
Hickory bitternut	Hb	
Hickory pecan		pn Hickory
Hickory mockernut		mn Hickory
Juniper eastern	Cr	
Larch tamarack	La	
Maple hard	Mh	
Maple red	Mr	
Maple silver	Ms	
Oak red	Or	
Oak white	Ow	
Oak swamp white	Osw	
Oak pin	Op	
Oak black	Obl	
Oak bur	Ob	
Oak chinquapin		
Pine white	Pw	
Pine red	Pr	
Pine jack	Pj	
Poplar largetooth	Al	
Poplar trembling	At	
Poplar balsam	Pb	
Spruce white	Sw	
Spruce black	Sb	
Sycamore	Sy	
Tolerant hardwoods	TH	
Tulip	Tt	
Walnut	Wb	

GLOSSARY OF SCIENTIFIC NAMES

Common Name	Scientific Name
acorn weevil	*Constrachelus* spp.
acorn weevil	*Curculio* spp.
anthracnose	*Gnomonia* spp.
armillaria (shoe string) rot	*Armillaria mellea* (Vahl ex Fr.) Kummer
ash borer	*Podosesia syringae fraxini* (Lugger)
ash flower gall mite	*Eriophyes (Aceria) fraxiniflora* Felt
ash fomes	*Fomes fraxinophilus* (Pk.) Sacc.
ash leaf rust	*Puccinia peridermiospora* (Ellis & Tr.) Arth.
ash leaf spot	*Mycosphaerella* spp.
ash sawfly	*Tethida* spp.
ash sawfly	*Tomostethus* spp.
ash yellows	mycoplasm
bald eagle	*Haliaeetus leucocephalus* (Linnaeus)
balsam fir	*Abies balsamea* (L.) Mill.
balsam poplar	*Populus balsamifera* L.
basswood	*Tilia americana* L.
bear	*Ursus americanus* Pallas
beaver	*Castor canadensis* Kuhl
beech	*Fagus grandifolia* Ehrh.
beech bark disease	*Nectria coccinea* var. *faginata* Lohman, Watson & Ayers
beech scale	*Cryptococcus fagi* (Baer.)
birch leaf miner	*Fenusa pusilla* (Klug)
birch leaf skeletonizer	*Bucculatrix canadensisella* Chamb.
bitternut hickory	*Carya cordiformis* (Wang.) K. Koch
black ash	*Fraxinus nigra* Marsh.
black bear	*Ursus americanus* Pallas
black-capped chickadee	*Parus atricapillus* Linnaeus
black cherry	*Prunus serotina* Ehrh.
black gum	*Nyssa sylvatica* Marsh.
black knot	*Dibotryon morbosum* (Schwein.) Theiss. & Sydow
black maple	*Acer nigrum* Michx. F.
black oak	*Quercus velutina* Lam.
black spruce	*Picea mariana* (Mill.) B.S.P.
black walnut	*Juglans nigra* L.
blue ash	*Fraxinus quadrangulata* Michx.
bronze birch borer	*Agrilus anxius* Gory
brown creeper	*Certhia americana* Bonaparte

Glossary cont.

Common Name	Scientific Name
brown cubical rot	*Coniophora cerebella* Pers.
brown mottled rot	*Pholiota spectabilis* (Fr.) Kummer
brown spongy heart rot	*Pholiota adiposa* (Fr.) Kummer
brown spongy heart rot	*Polyporus glomeratus* Peck
Bruce spanworm	*Operophtera bruceata* (Hulst)
bur oak	*Quercus macrocarpa* Michx.
butternut	*Juglans cinerea* L.
cambial miner	*Agromyza* spp.
cambial miner	*Phytobia* spp.
carpenterworm	*Prionoxystus robiniae* (Peck)
chinquapin oak	*Quercus muehlenbergii* Engelm.
Columbian timber beetle	*Corthylus columbianus* (Hopkins)
Cooper's hawk	*Accipiter cooperii* (Bonaparte)
coyote	*Canus latrans* (Say)
cytospora canker	*Cytospora (Valsa) pruinosa* (Fr.) Hohnel
cytospora canker	*Valsa sordida* Nitschke
eastern juniper	*Juniperus virginiana* L.
eastern tent caterpillar	*Malacosoma americanum* Dyar
eutypella canker	*Eutypella parasitica* Dav. & Lor.
fall webworm	*Hyphantria cunea* (Drury.)
fisher	*Martes pennanti* (Erxleben)
forest tent caterpillar	*Malacosoma disstria* Hbn.
fox	*Vulpes vulpes* (Linnaeus)
great horned owl	*Bubo virginianus* (Gmelin)
green ash	*Fraxinus pennsylvanica* var. *subintegerrima* (Vahl) Fern.
grouse (ruffed)	*Bonasa umbellus* (Linnaeus)
gypsy moth	*Lymantria dispar* (Linnaeus)
hard (sugar) maple	*Acer saccharum* Marsh.
hare	*Lepus* spp.
hemlock	*Tsuga canadensis* (L.) Carr.
hemlock borer	*Melanophila fulvoguttata* (Harr.)
hemlock looper	*Lambdina fiscellaria* var. *fiscellaria* (Guen.)
heron (great blue)	*Ardea herodias* Linnaeus
jack pine	*Pinus banksiana* Lamb.
kestrel	*Falco sparverius* (L.)
larch (tamarack)	*Larix laricina* (Du Roi) K. Koch
largetooth aspen (poplar)	*Populus grandidentata* Michx.
leaf rusts	*Melampsora* spp.

Glossary cont.

Common Name	Scientific Name
lynx	*Lynx canadensis* (Linnaeus)
marten	*Martes americana* (Turton)
mice	*Napaeozapus* spp., *Peromyscus* spp., *Zapus* spp.
mink	*Mustela vison* (Schreber)
mockernut hickory	*Carya tomentosa* Nutt.
moose	*Alces alces* (Linnaeus)
northern goshawk	*Accipiter gentilis* (Linnaeus)
oak leaf shredder	*Croesia semipurpurana* (Kft.)
oak skeletonizer	*Bucculatrix ainsliella* (Murteldt)
oak wilt	*Ceratocystis fagacearum* (Bretz) Hunt
oak canker	*Dothiorella quercina* (Cooke & Ell.) Sacc.
osprey	*Pandion haliatus* (Linnaeus)
otter	*Lutra canadensis* (Schreber)
peach bark beetle	*Phloeotribus liminaris* (Harris)
peach tree borer	*Sanninoidea exitiosa* (Say)
pear thrips	*Taeniothrips* spp.
pecan hickory	*Carya illinoensis* (Wangenh.) K. Koch
peregrine falcon	*Falco peregrinus* Tunstall
pileated woodpecker	*Dryocopus pileatus* (Linnaeus)
pin oak	*Quercus palustris* Muenchh.
porcupine	*Erethizon dorsatum* (Linnaeus)
raccoon	*Procyon lotor* (Linnaeus)
red ash	*Fraxinus pennsylvanica* Marsh.
red-backed vole	*Clethrionomys* spp.
red belt fungus	*Fomes pinicola* (Schwartz) Cke.
red heart rot	*Stereum sanguinolentum* (Alb. & Schw. ex Fr.) Fr.
red maple	*Acer rubrum* L.
red oak	*Quercus rubra* L.
red oak borer	*Enaphalodes rufulus* (Haldeman)
red pine	*Pinus resinosa* Ait.
red-shouldered hawk	*Buteo lineatus* (Gmelin)
red (slippery) elm	*Ulmus rubra* Muhl.
red spruce	*Picea rubens* Sarg.
red-tailed hawk	*Buteo jamaicensis* (Gmelin)
rock elm	*Ulmus thomasii* Sarg.
root and butt rot	*Corticium galactinum* (Fr.) Burt
ruffed grouse	*Bonasa umbellus* (Linnaeus)
rusty conk	*Polyporus gilvus* (Schw.) Fr.
saddled prominent	*Heterocampa guttivitta* (Wlk.)

Glossary cont.

Common Name	Scientific Name
sapstreak disease	*Ceratocystis (Endoconidiophora) virescens* (Davidson)
sassafras	*Sassafras albidum* (Nutt.) Nees
saw-whet owl	*Aegolius acadicus* (Gmelin)
screech owl	*Otus asio* (Linnaeus)
shag bark hickory	*Carya ovata* (Mill.) K. Koch
silver maple	*Acer saccharinum* L.
snowshoe hare	*Lepus americanus* Erxleben
spongy white heart rot	*Polyporus hispidus* (Bull.) Fr.
squirrel	*Tamiasciurus* spp.
strumella canker	*Strumella coryneoides* Sacc. & Wint.
sugar maple borer	*Glycobius speciosus* (Say)
sulphur fungus	*Laetiporus (Polyporus) sulphureus* (Bull. ex Fr.) Bond. & Sing.
swamp white oak	*Quercus bicolor* Willd.
sycamore	*Platanus occidentalis* L.
target canker	*Nectria galligena* Bresad.
trembling aspen	*Populus tremuloides* Michx.
tulip tree	*Liriodendron tulipifera* L.
ugly nest caterpillar	*Archips cerasivoranus* (Fitch)
white (american) elm	*Ulnus americana* L.
white ash	*Fraxinus americana* L.
white birch	*Betula papyrifera* Marsh.
white cedar	*Thuja occidentalis* L.
white heart rot	*Inonotus (Poria) Andersonii* (Ell. & Ev.) Cerny
white heart rot	*Polyporus berkeleyi* Fr.
white heart rot	*Stereum murraii* (Berk. & Curt.) Burt
white oak	*Quercus alba* L.
white pine	*Pinus strobus* L.
white pocket rot	*Stereum frustulatum* (Pers. ex Fr.) Fckl.
white pocket rot	*Stereum gausapatum* (Fr.) Fr.
white rot	*Polyporus compactus* Overh.
white spongy heart rot	*Fomes igniarius* (L. ex Fr.) Kickx
white spruce	*Picea glauca* (Moench) Voss
white-tailed deer	*Odocoileus virginianus* (Zimmermann)
wolf	*Canis lupus* (Linnaeus)
wood duck	*Aix sponsa* (Linnaeus)
yellow-bellied sapsucker	*Sphyrapicus varius* (Linnaeus)
yellow birch	*Betula alleghaniensis* Britt.
yellow birch canker	*Diaporthe alleghaniensis* Arnold